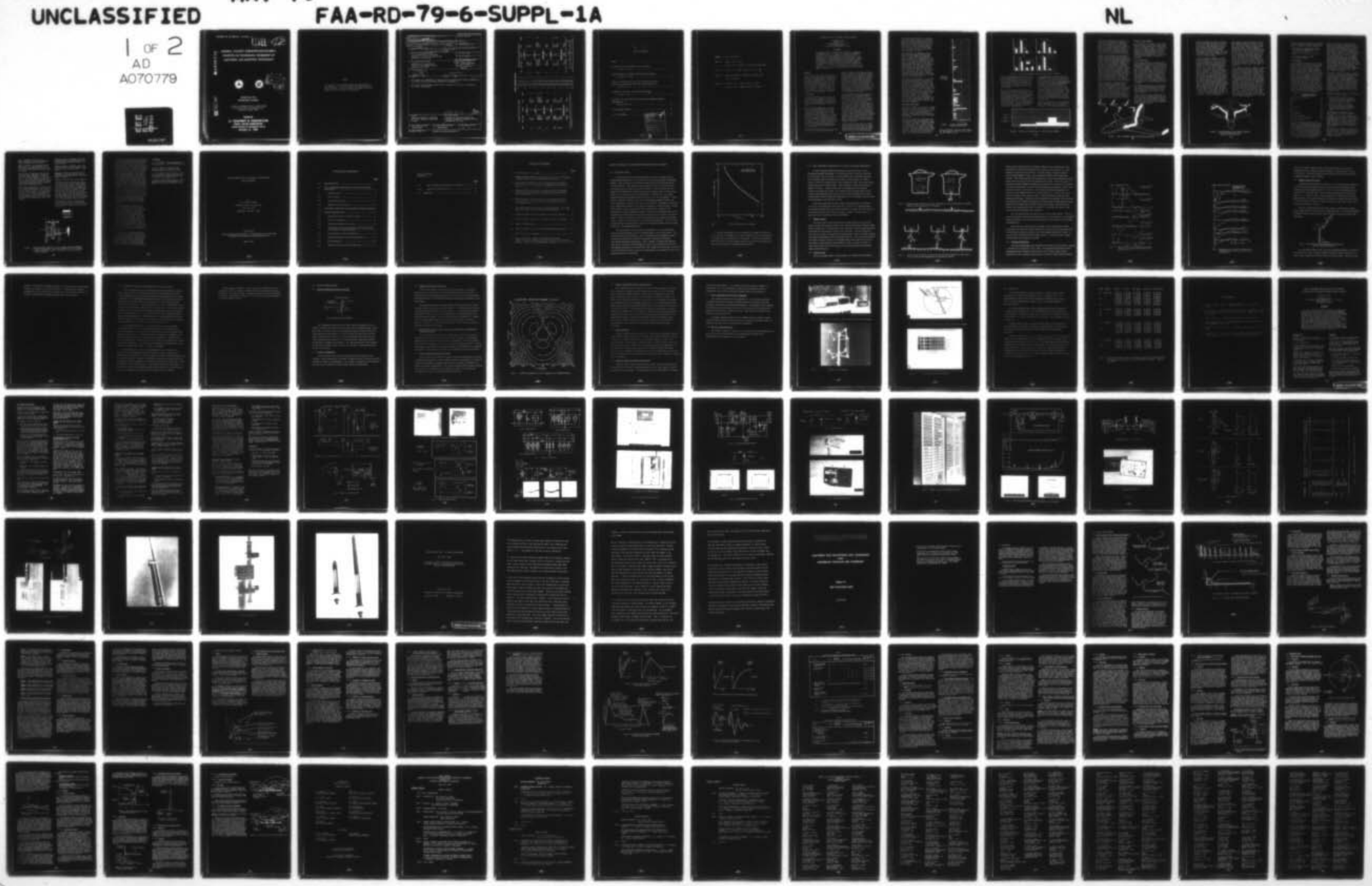
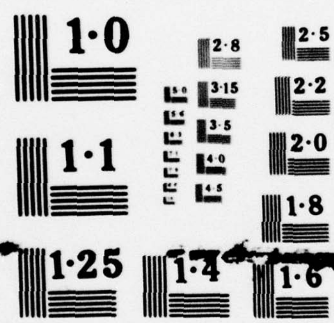
AD-A070 779 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC SYSTEM--ETC F/G 4/1
FEDERAL AVIATION ADMINISTRATION - FLORIDA INSTITUTE OF TECHNOLO--ETC(U)
MAY 79

UNCLASSIFIED FAA-RD-79-6-SUPPL-1A NL

1 OF 2
AD
A070779





NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

REPORT NO. FAA-RD-79-6 SUPPLEMENT 1A

FEDERAL AVIATION ADMINISTRATION-FLORIDA INSTITUTE OF TECHNOLOGY WORKSHOP ON GROUNDING AND LIGHTNING TECHNOLOGY

MARCH 6-8, 1979

MELBOURNE, FLORIDA

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared By

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Systems Research & Development Service

Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
14 FAA-RD-79-6 Suppl[redacted]t-1A		

4. Title and Subtitle	5. Report Date
6 Federal Aviation Administration - Florida Institute of Technology Workshop on Grounding and Lightning Technology Held on 6-8 March 1979 Melbourne, Florida. Supplement IA.	May 1979
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
9. Performing Organization Name and Address Florida Institute of Technology Department of Electrical Engineering Melbourne, Florida 32901	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Washington, DC 20590	13. Type of Report and Period Covered 9 Final rept. March 6-8, 79 14. Sponsoring Agency Code ARD-350

15. Supplementary Notes

12 99p. 11 May 79

16. Abstract

A065410

This report is a supplement to Federal Aviation Administration Report FAA-RD-79-6 dated March 1979 and supersedes FAA-RD-79-6 Supplement 1. (A)

The report contains papers which were not available in time to be included in the orginal proceedings.

A065410

340 170 JM

17. Key Words	18. Distribution Statement
Lightning protection, lightning detection, transient protection, aircraft.	Document is available through the National Technical Information Service, Springfield, VA 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	92	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

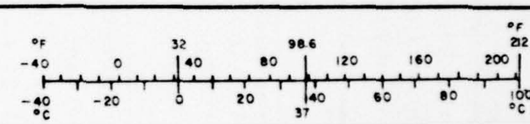
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Partial

TABLE OF CONTENTS

<u>ERRATA</u> for report FAA-RD-79-6

Page 21: Change title to read

"Measurements on Natural and Triggered Lightning"

Page 72: Formula $V(t) = \frac{di}{dt}$ Should be $V(t) = L\frac{di}{dt}$

Page 122: Second paragraph of "Diagnostics" change last line to "or d.c."

Page 125: References (2) change "3659" to "3855"

References (11) change "Gajola" to "Gajda"

LIGHTNING EFFECTS ON GENERAL AVIATION AIRCRAFT

J. Anderson Plumer
President
Lightning Technologies, Inc.
560 Hubbard Avenue
Pittsfield, Massachusetts 01201

BIOGRAPHY

J. Anderson Plumer is founder and president of Lightning Technologies, Inc. He began his career at the General Electric High Voltage Laboratory, conducting studies of dielectric breakdown phenomena and lightning effects on aircraft fuel, structural and electrical systems. He was instrumental in the development of new laboratory methods for the study of lightning effects on aircraft and has contributed to industry groups working toward education and standardization of lightning protection methods and techniques. Mr. Plumer is co-author of the book *Lightning Protection of Aircraft* and was named the recipient of the Admiral Luis de Florez Flight Safety Award in 1978 for his work in this area.

ABSTRACT

The availability of IFR avionics and improved pilot training has increased the exposure of business and general aviation aircraft to adverse weather conditions, including lightning strikes; sometimes with hazardous results. With the cooperation of FLIGHT OPERATIONS magazine, a lightning strike reporting project has been implemented to identify potential problem areas and alert designers of future aircraft. Initial findings from this expanding data base are presented, together with implications for design.

INTRODUCTION

The highly competitive marketplace and increasing cost of energy is motivating manufacturers of general aviation aircraft to achieve greater efficiency and economy through application of advanced technologies in the design of new aircraft.

Some of the new technology structural materials and manufacturing techniques now on the drawing board may be more vulnerable to electrical hazards than conventional structures due to their reduced electrical conductivity. Among these are the use of advanced composite materials in place of aluminum, and adhesive bonding in place of mechanical fasteners. Some of these new materials are already in use, albeit mostly in noncritical applications, but other aircraft now on the drawing board plan to utilize composites and adhesives much more extensively.

Inhibiting some applications of these new technologies, however are potential problems posed by environmental effects such as lightning. Just as the entire structure must safely accept and tolerate the mechanical loads imposed by flight, it must also conduct electric currents produced by the lightning and on-board systems, and conduct these through itself without degradation of mechanical integrity and without hazardous side-effects such as electrical sparking. The electrical and electronics systems contained within these structures must also be designed to tolerate the increased electromagnetic fields which may penetrate nonmetallic structures.

Since an aircraft has little effect on the magnitude of lightning current it may receive, the structure of small, general aviation aircraft must be capable of conducting just as many amperes of lightning current as must that of jumbo jet. As a result, the *density of current* in the skins, ribs and spars of a small aircraft can be much higher that the density of current flowing through the larger aircraft. Since the electrical energy that must be tolerated within a given volume of structure is proportional to the square of the current density, the task of protecting the smaller aircraft from structural damage, internal sparking, and related effects is fundamentally more challenging than protection of larger aircraft which have more massive structures into which lightning currents can spread.

At first glance, protection for these small aircraft seems to imply the addition of protective diverters, coatings, shields, bonds and other measures whose weight and cost would negate the advantages provided by the new-technology

structures and electronics. This need not be the case, however, if innovative protective measures are developed and applied only where needed; but to avoid pitfalls this course requires that more definitive information be obtained on the location of the lightning strike zones on small aircraft and the magnitude of damage that the higher current concentrations can cause.

Until recently, no system has been in place for obtaining information from the in-flight strikes that presently occur. In many cases the damage is simply repaired and valuable information, which is important to designers of aircraft now on the drawing board, has been lost. In an effort to fill this gap, FLIGHT OPERATIONS magazine and Lightning Technologies, Inc. have begun a pilot reporting project utilizing a tear-out questionnaire published periodically in the magazine. Thanks to the cooperation of reader-pilots, the lightning reporting project has begun to produce information of significance to those who operate small aircraft as well as those engaged in aircraft design.

The object of this project is to provide the information necessary to design of effective and efficient lightning protection for small aircraft, and to help pilots avoid it whenever possible. The lightning strike questionnaire was first printed in the November 1977 issue[1] and next in July 1978[2]. These questionnaires produced 40 responses, most of which described recent strikes. A few readers also provided data on lightning strikes experienced several years before; a testimony, perhaps, to the lasting impressions left by these experiences. Some of the more important findings thus far, and the implications they have for protection design, are presented in the following paragraphs.

CONDITIONS WHEN STRUCK

While forty reports is too small a sample upon which to base conclusions, it is of interest to chart some of the information in formats from which conclusions can later be drawn as the data expands. Figure 1, for example, shows the flight altitudes at which the first 40 aircraft were struck.

As shown in Figure 1, strikes occurred at virtually all flight altitudes, with the highest percentage happening between 5,000 and 15,000 feet. 45,000 feet was the highest altitude at which a strike was encountered, as reported by a Lear Jet operator after a flight from Panama to Miami. The lightning strike occurred while the aircraft was penetrating the top of a cumulonimbus (CB) cloud over Cuba. Air Traffic Control would not allow a deviation, and the strike caused the left engine to flame out and burned out both ADF receivers.

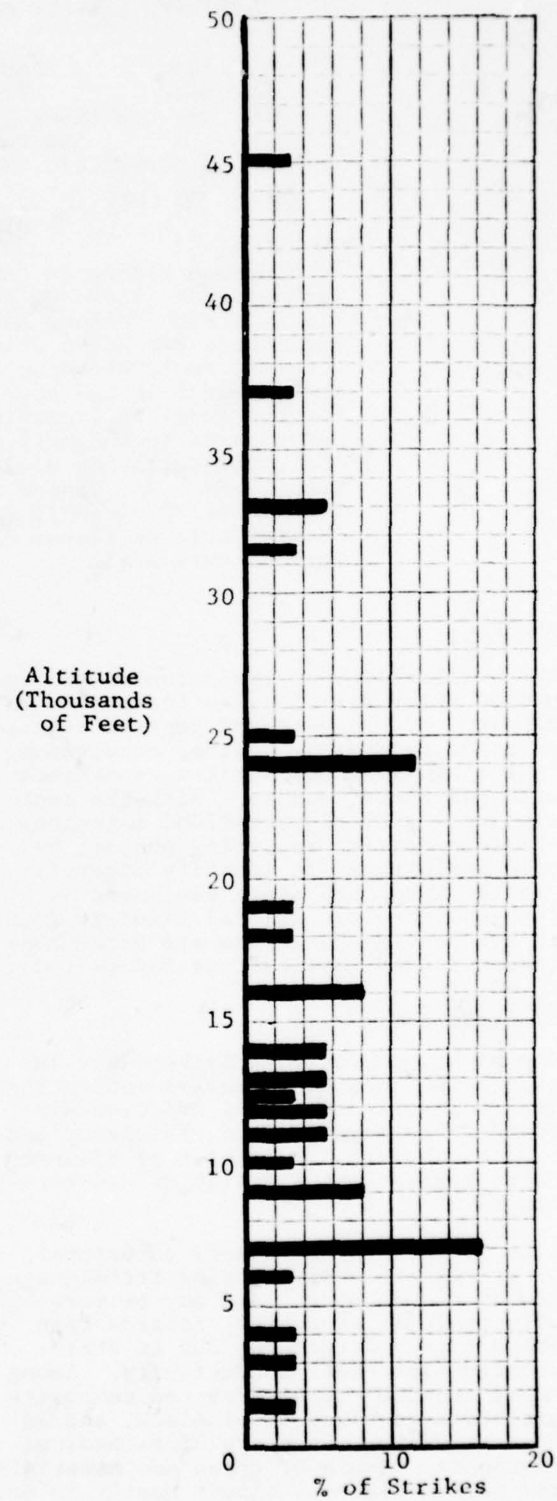


FIGURE 1 - FLIGHT ALTITUDES WHERE AIRCRAFT WERE STRUCK.

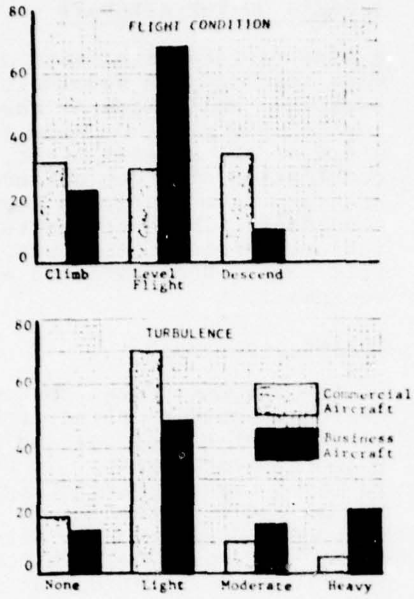


FIGURE 2 - FLIGHT AND WEATHER CONDITIONS WHEN STRIKES OCCURRED.

All of the strikes reported above 24,000 feet were experienced by jet-powered aircraft, whereas most of those at 24,000 feet and below involved piston or turboprop aircraft that commonly operate at these lower altitudes. The wide range of altitudes, of course, indicates that aircraft are never beyond reach of lightning strikes.

The other conditions within which the pilots found themselves when the reported strikes occurred are summarized on Figures 2 and 3. Figure 2 shows the flight and weather conditions, with a comparison to the commercial aircraft experience determined from a related project[3]. Most strikes happened while the aircraft was in level flight, within a cloud, and experiencing some form of precipitation and light turbulence. Figure 3 shows that the outside air temperature was also close to the freezing point.

The precipitation and cloud conditions revealed here are similar to those experienced by commercial aircraft, but at first glance the comparisons indicate a marked difference in the flight condition and degree of turbulence experienced. The higher percentage of strikes reported to business aircraft in *level flight* probably reflects the fact that most of these aircraft cruise at lower altitudes than their big brothers, where lightning strikes are more common. Likewise, the higher percentages of *moderate* and *heavy* turbulence noted by the business aircraft operators simply acknowledge the unfortunate fact that smaller aircraft bounce further than larger ones in choppy air.

The data of Figures 1, 2 and 3 indicate that an aircraft flying at between 5,000 and 15,000 feet, within a cloud (not necessarily a CB) and experiencing some

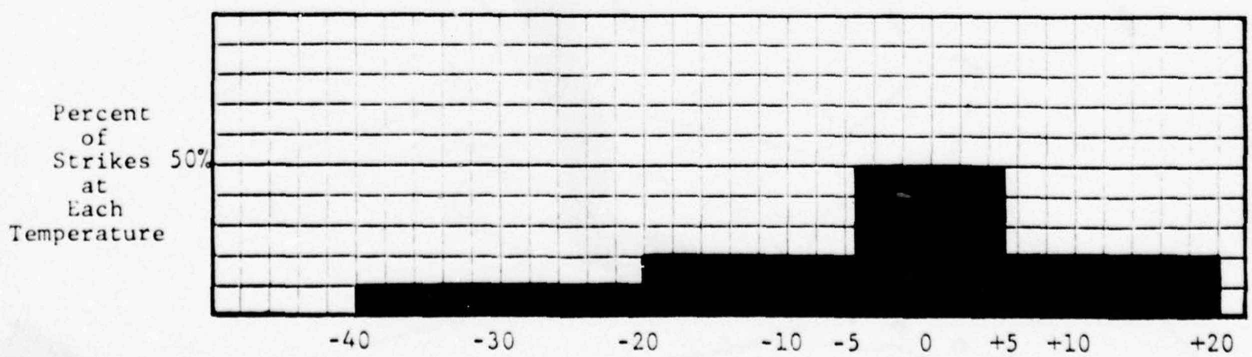


FIGURE 3 - OUTSIDE AIR TEMPERATURE (°F) WHEN STRIKES OCCURRED.

form of precipitation and turbulence is most likely to receive a lightning strike. To avoid all of these conditions would greatly reduce the probability of a strike, but such a practice would also relegate many aircraft to a life in a hangar. Instead, the data (as it develops) should be interpreted to alert pilots of the conditions within which a lightning strike is most likely.

Indeed, quite a few of the reported incidents occurred when least expected. Most of the pilots were either completely unaware of any thunderstorm activity in their vicinity or circumnavigating known areas of activity when the strikes occurred. One, for example, reported that the nearest thunderstorm (as defined by radar returns) was 150 miles behind. He was in solid stratus clouds at 37,000 feet and beginning to encounter turbulence when the strike occurred. Several others reported circumnavigating storm echoes by 30 miles when they were zapped. Only two reports were received of aircraft passing close to or penetrating a line of thunderstorms, and in these cases the aircraft were near terminal areas and being vectored from the ground.

Electrical charge accumulations sufficient to support a lightning flash nearly always originate in CB-type clouds, but charge from such a cloud can be carried a hundred or more miles downwind by its anvil blow-off. Precipitation such as sleet and hail can also be carried away in this manner, and since ice particles are invisible to most radars, such an area may be encountered unexpectedly. The resulting lightning, hail and turbulence can be quite a surprise.

EFFECTS ON THE AIRCRAFT

A wide variety of effects on the aircraft were reported, in seemingly random combinations. While none of these resulted in loss of the plane or harm to those inside, a few of the effects might, in another combination or under different circumstances, have developed more serious consequences. Those of greatest concern included engine flame-outs, loss of electric power, and damage to electronic equipment.

Engine Flame-Outs

Of the eleven strikes to turbojet aircraft reported thus far, four resulted in flameout of one engine and a fifth caused both engines to quit. It was possible to re-light the engine in flight in all but two of these instances, in which restarts were not possible until after the aircraft had landed. The aircraft that lost both engines was struck at 31,500 feet and in spite of repeated attempts, the engines would not start again until the aircraft had descended to 13,000 feet. One instance of a turbo-prop engine flaming out has also been reported, with an in-flight re-start being obtained shortly afterwards.

The high percentage of biz-jet flameouts that result when lightning strikes occur has prompted some operators to ask for more information on this subject, and whether anything can be done to prevent these flameouts.

Study of these incident reports and discussions with the operators involved reveals that the engine flameouts are probably caused by the disruption of inlet air which results when the hot lightning channel is swept in front of an engine as illustrated in Figure 4.

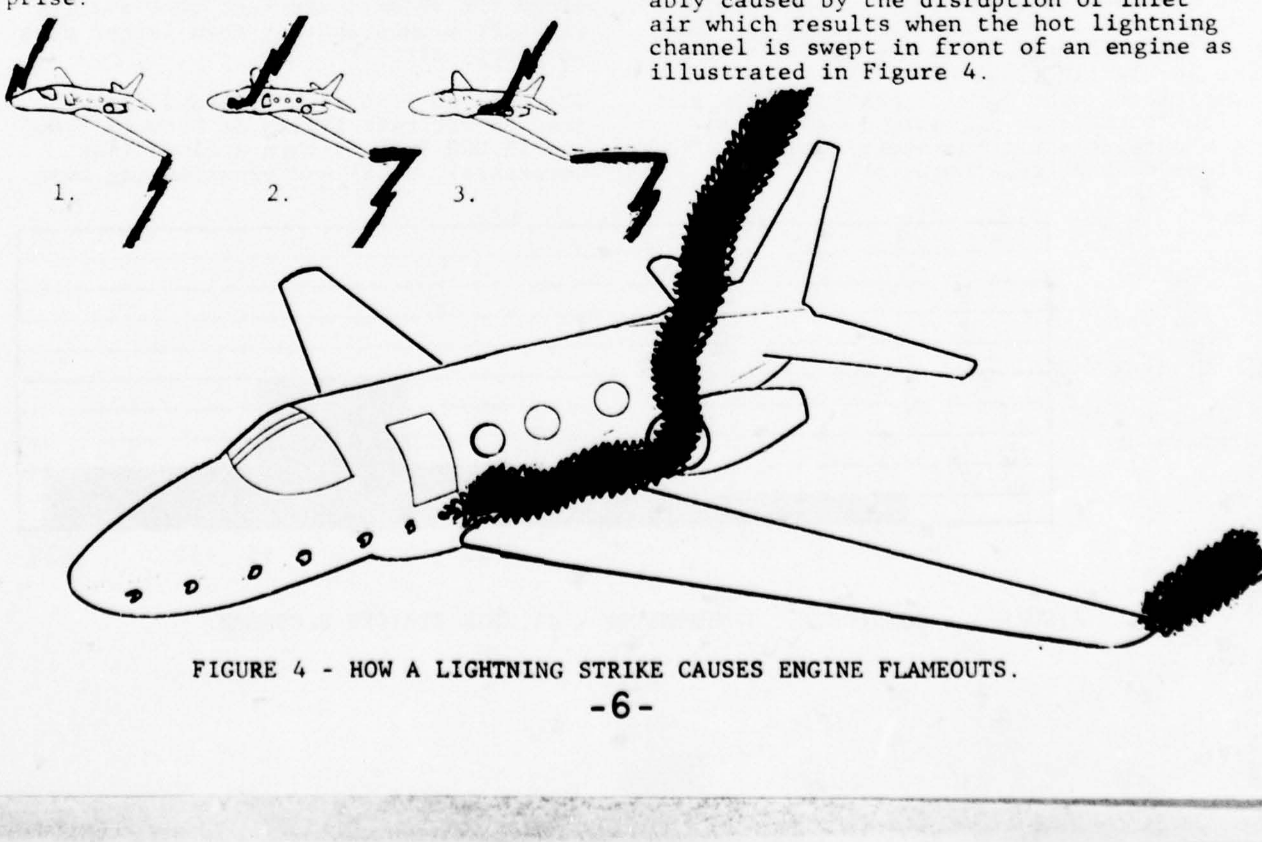


FIGURE 4 - HOW A LIGHTNING STRIKE CAUSES ENGINE FLAMEOUTS.

Lightning flashes, of course, initially attach to extremities such as the nose or wing tips, but since the aircraft is moving, the lightning channel will become elongated and reattach to other spots aft of the initial attachment point as illustrated in the insert. Items mounted on the fuselage, including the engines, may thus be exposed to the lightning channel even if they are not struck in the first place.

A typical lightning channel is a long, tortuous column of luminous, electrically conductive air. It may be a foot or more in diameter, and at its center, temperatures as high as 30,000°K and pressures of many atmospheres may be reached. It is not hard to imagine how this unruly visitor can disrupt the orderly flow of air into a small jet engine, sufficient to cause a compressor stall or flameout. Whereas the lightning channel may pass very close to the engine inlet, it is not possible for this electrical conductor to be ingested because the lightning channel will simply reattach to the inlet cowling which is itself conductive. The tell-tale burn marks found on engine inlets after several of the reported strikes confirm this. The reasons that lightning-related engine flameouts do not occur to transport category aircraft with fuselage-mounted engines are (1) that the flash has died before being swept the longer distance back to the engine intakes, and (2) that the intakes themselves are larger and a flash might not disrupt sufficient air to stall the engine.

Some operators have asked whether the engine flameouts might be due to a lightning related disruption of electric power or to some other indirect effect of the lightning strike. Since no damage to engine electronics or fuel pumps has been reported it appears that such effects are not the cause. Also, while loss of electric power was indeed reported in a number of incidents, they don't happen to be the ones that involved engine flameouts. The difficulty in obtaining inflight re-starts after these flameouts may be the result of flooding, since precipitation was also reported in four out of the five incidents. Rain was reported in two of the three cases of re-start difficulty.

As for protection against flameouts, there is no protective device or design change presently known that would improve the situation, although these incident reports have prompted researchers to begin discussions of how the effect might be simulated in the laboratory - a first step toward learning more about the intensities of temperature and overpressure required to disrupt these engines, and the extent to which they are related to engine power settings. Fortunately, some comfort can be derived from the fact that in most cases only one engine flames out. This is logical because the lightning flash usually sweeps along only one side of the fuselage. In the case where both engines flamed out, the strike must have swept along both sides at once. In this case the lightning strike must have entered one side of fuselage and exited from the other side, as shown in Figure 5.

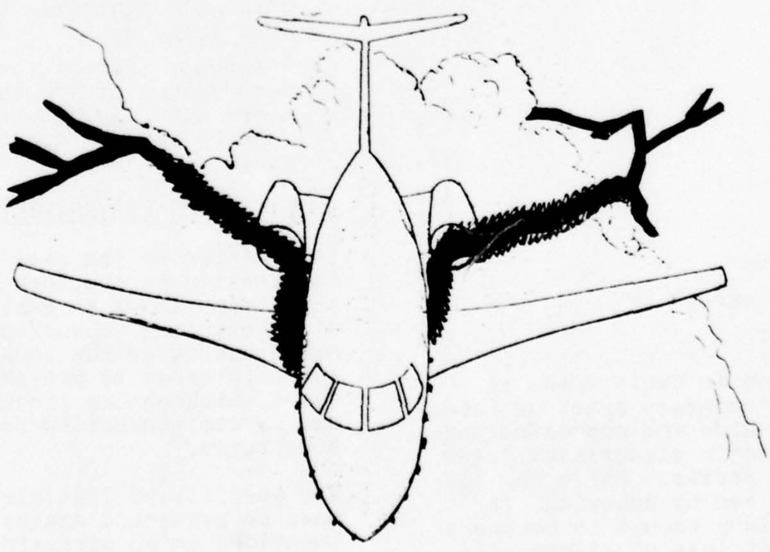


FIGURE 5 - POSSIBLE CAUSE OF DUAL ENGINE FLAMEOUTS.
• The strike enters one side and exits from the other.

Therefore, at least until more is learned about the flameout problem, the best advice for operators of small aircraft is:

- Be aware that lightning may cause flameouts (to turbo-props as well as turbo-jet aircraft)
- Avoid areas of heavy precipitation, and
- Be familiar with in-flight re-start procedures

Power Outages

Loss of alternator and/or inverter power was reported in 8 of the 40 strike incidents. In most cases this was temporary and power was restored after circuit breakers were re-set. The particular causes of each power outage are unknown, since determination of these would require inspection of the aircraft or electrical circuits involved. It is probable, however, that the lightning strikes induce overvoltage 'spikes' in the electrical wiring, of sufficient magnitude to spark across the insulation of terminal boards, lamp sockets and other devices, causing short circuits. The circuit breakers pop and clear these faults, but not before the lightning surges have also passed into electronic equipment power supplies, sometimes causing them to burn out. Types of equipment reported to have suffered damage and the number of incidents of each are listed in Table I.

TABLE I - Equipment Damaged by Lightning Strikes

Autopilot Pitch Controls	(1)
Radar Set	(1)
VOR	(1)
ILS	(1)
ADF	(4)
VHF Comm Set	(3)
DME	(2)
Tail Light	(1)
DC Generators	(1)
Encoding Altimeter	(1)
Telephone and Telegraph Set	(1)
Windshield Heater	(1)

The outages listed in Table I are in addition to the temporary upset or interference with NAV-aids and communication gear caused by static electricity prior to the lightning strike. While the latter interference can by annoying, it rarely persists long enough to become a hazard. Permanent loss of electronics however, especially if widespread, could deprive a pilot of flight instruments and NAV-aids critical to successful flight around hazardous weather.

Many of the voltage surges mentioned above are coupled into the aircraft's wiring by the magnetic fields that accompany every lightning strike, but some surges have been injected directly into the aircraft by strikes to navigation and position lights. If a strike lands near a light, a globe may break and allow some of the lighting current to enter the lamp power wires. If this happens some of the wires may also be damaged. All lamps should therefore be inspected after a strike occurs and if a lamp has been damaged, the insulation on the wiring and other components between the lamp and the load center should also be inspected for damage. If other lamps are powered from the same circuit breakers, the wiring out to these lamps should also be inspected, even if the lamps themselves were not damaged.

At present, there exist almost no devices that can be purchased and conveniently installed on an existing aircraft to protect electronics against lightning-induced surges. Surge protection, instead, is easiest to incorporate during design and manufacture of new aircraft. Incorporation of it has begun, and will evolve as understanding of the problem improves. Eventually, industry-wide standards will define protection levels and establish responsibilities of the electronics manufacturer as well as the aircraft builder.

Meanwhile, rules of thumb for operators to follow now should include:

- Be sure that all electrical and electronic equipment is operative before taking off, so that backup units are available if the No. 1 unit fails due to a strike
- Carefully inspect the aircraft for damaged wiring or components after a strike and have necessary repairs made before flying again

IMPLICATIONS FOR PROTECTION DESIGN

In addition to the data reviewed above, information on the location of lightning attachment zones on small aircraft is also beginning to surface. Design engineers must know the location of these zones in order to provide skins of adequate thickness to protect fuel tanks, and to add protection for non-metallic structures.

The severity of lightning currents which must be protected against at particular locations on an aircraft depends on the *lightning strike zone* of the location of concern. Three basic zones have been defined[4] as follows:

Zone 1: Surfaces where there is high probability of initial lightning flash attachment (entry or exit),

Zone 2: Surfaces of the vehicle across which there is a high probability of a lightning flash being swept by the airflow from a Zone 1 point of initial flash attachment,

Zone 3: Zone 3 includes all of the vehicle areas other than those covered by Zone 1 and Zone 2 regions. In Zone 3 there is a low probability of any attachment of the direct lightning flash arc. Zone 3 areas may carry substantial amounts of electrical current but only by direct conduction between some pair or direct or swept stroke attachment points,

and further divides Zones 1 and 2 into A and B regions depending on the probability that the flash will hang on for any protracted period of time. An A-type region is one in which there is low probability that the arc will remain attached and a B-type region is one in which there is a high probability that the arc will remain attached. Some examples of zones are as follows:

Zone 1A: Initial attachment point with low probability of flash hang-on, such as the forward and middle portion of a wing-tip tank.

Zone 1B: Initial attachment point with high probability of flash hang-on, such as the aft end (trailing edge) of a tip tank.

Zone 2A: A swept stroke zone with low probability of flash hang-on, such as the wing surfaces and nacelle tank skins behind a propeller.

Examples of these zones are on Figure 6.

The forward end of the wing-tip tank is in Zone 1A. Due to the forward motion of the aircraft, however, and the need for the lightning leader to continue to the ground before the return stroke occurs, arcs initially striking the forward tip will be swept aft and it is quite possible that, in some cases at least, the high-amplitude return stroke current will not appear until the arc has reattached several feet aft of the forward tip. Thus the center surface of the tank must also be assumed to be in Zone 1A.

If the flash is still alive when the trailing edge passes by, the arc will hang on to this location until the flash dies naturally, placing the aft tip in Zone 2B.

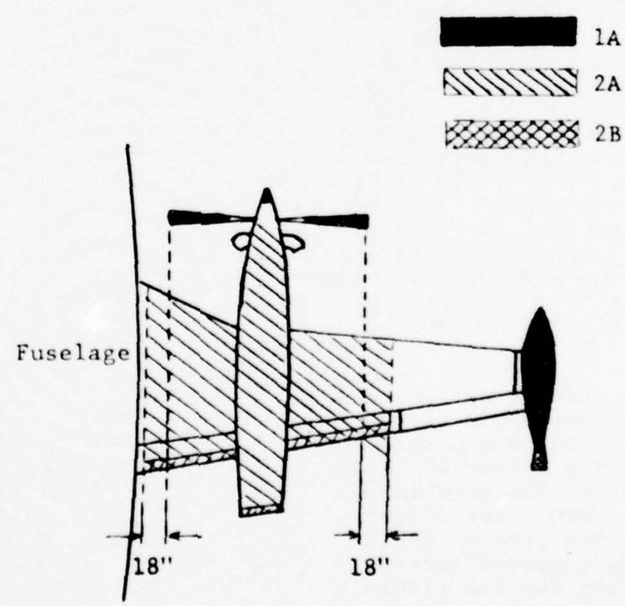


FIGURE 6 - LIGHTNING STRIKE ZONES ON A TYPICAL GENERAL AVIATION AIRCRAFT.
- The 18" extensions of Zone 2A on either side of the propelier diameter account for lateral variations in the arc path Aft of the propeller.

For years the airlines and manufacturers of commercial aircraft have recorded the location of the holes and burned marks left by lightning strikes, for use in establishing the lightning strike zones on these aircraft. But to date, no such data base exists for business and general aviation aircraft. Most designers have therefore adopted the zones established for commercial aircraft, but initial data from this project indicates there may be some differences. For example, Zone 1A (defined as "a direct strike zone with low probability of flash hang-on") includes only the nose area of a transport aircraft fuselage, but several of the reports from this project show evidence of direct strikes arriving well aft of the nose. This fact is undoubtedly due to the shorter length of these aircraft. *Even though the leader may initially attach to the nose of the aircraft, the aircraft may have flown ahead nearly its entire length before the leader reaches the earth and the damaging return stroke is initiated - thus allowing the return stroke to arrive nearly anywhere on the small aircraft fuselage.* This result suggest that the entire fuselage of most business and general aviation aircraft should be considered within Zone 1A for protection design purposes.

Fortunately perhaps, lightning is an elusive phenomena which doesn't stay around long enough to be conveniently studied. Over the years a lot has been learned about lightning from patient efforts to photograph it, and from measurements of the electric currents it deposits in tall structures such as the Empire State Building. Lightning currents can be reproduced with large capacitor banks in the laboratory for study of the effects these currents have on individual airplane parts. But the answers to other important questions, including the engine effects and strike zones discussed above, would require man-made lightning tests of a complete aircraft in its own habitat - a practial impossiblity.

The best answers to these questions will come instead from nature's own tests - as reported by the pilots who chance to be first hand witnesses. However insignificant they may seem, the burn marks, circuit-breaker pops and other effects can help warn of future problem areas and pay dividends in improved safety. Thanks, therefore, are due the pilots who take the time to report these events.

REFERENCES

1. J.A. Plumer, "Lightning Protection: How You Can Help, FLIGHT OPERATIONS, Nov. 1977, p. 29.

2. J.A. Plumer, "Lightning Strike Feedback: More Pilot Reports Needed", FLIGHT OPERATIONS, July 1978, p. 42.

3. J.A. Plumer and B.I. Hourihan, "Data from the Airlines Lightning Strike Reporting Project", General Electric R&D Report GPR-75-004, March 1975.

4. Report of SAE Committee AE4L, "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware", June 1978.

A NEW APPROACH TO LIGHTNING POSITIONING AND TRACKING

by

Dr. Rodney B. Bent
Atlantic Scientific Corporation
P. O. Box 3201
Indialantic, Florida 32903

Presented at
Federal Aviation Administration - Florida Institute of Technology
Workshop on Grounding and Lightning Protection

March 1979

TABLE OF CONTENTS

Table of Contents
Continued ......

LIST OF FIGURES

A NEW APPROACH TO LIGHTNING POSITIONING AND TRACKING

1.0 INTRODUCTION

Crossed-loop direction-finding methods have been routinely used in multistation applications for over 30 years to locate the positions of lightning flashes. Such methods were developed during World War II and operate at VLF frequencies. The methods are especially effective in the surveillance of thunderstorms at distances of 500 to 3000 km. This is because the VLF signals from lightning are large and they also propagate well, so that strong pulses are received even from distant flashes. Furthermore, for ranges beyond 500 km,site and polarization errors are not a severe problem. Within 500 km, however, bearing errors,due to horizontally polarized fields, are very troublesome in routine VLF sferics DF systems. Ionospheric reflections cause polarization changes of the signal at distances of 100 to 500 km. Within some 200 km, major horizontal fields are generated by radiation from horizontally orientated lightning channels, and also by subsequent pick-up and reradiation of these fields by horizontal conductors such as fences and buried cables. Figure 1 illustrates some recent Japanese data relating the bearing error to range for conventional VLF crossed-loop techniques. It is seen that within 100 miles VLF detection results in errors greater than 25°, thus making location of close lightning difficult.

The initial part of an incoming VLF atmospheric is more dominantly vertically polarized than are the succeeding stages as one would expect. The first portion of the ground pulse, since it originates in the lightning channel section most likely to be vertically orientated, contains the minimum horizontally polarized contribution. Thus, "gating" techniques that operate only on the first part of the atmospheric, much reduce polarization troubles. Such gating methods were incorporated in the original British design of a sferics locator,[1] primarily with the objective of operating on the groundwave only, and of ignoring skywave contributions.

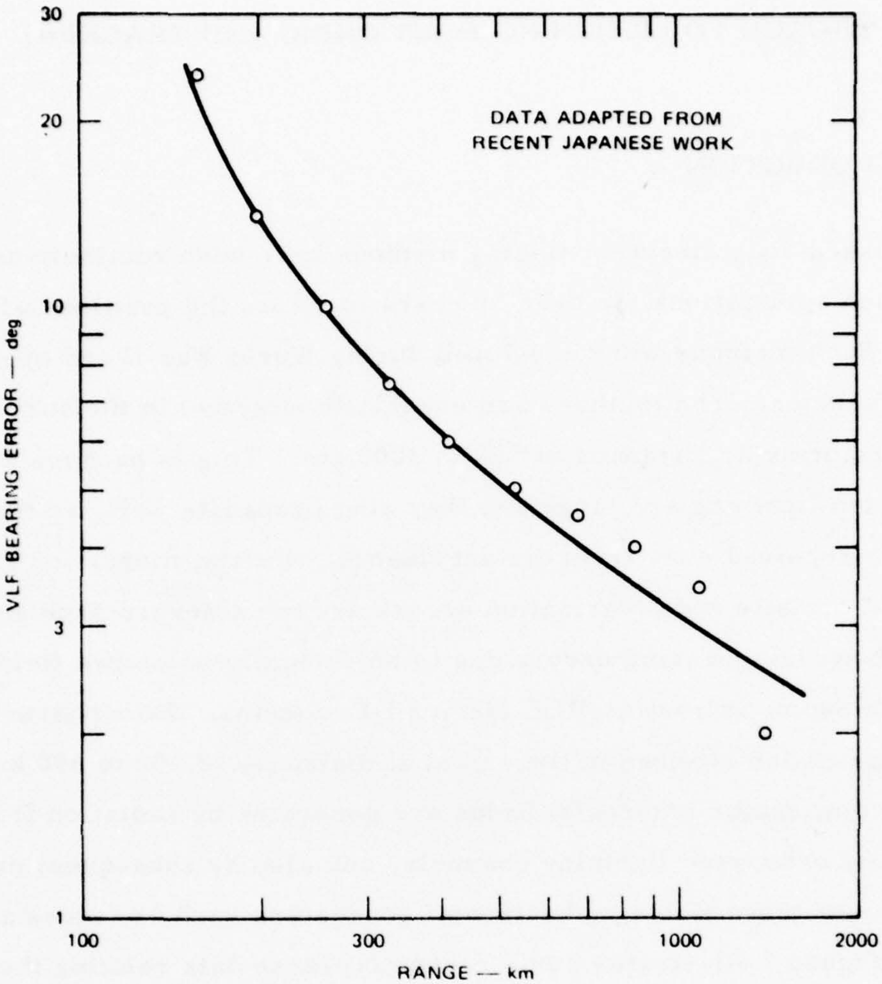


Fig. 1 VLF Bearing Error Vs. Range

A similar gating approach was suggested by Latham and Uman in 1971, and also by Noggle et al [2] and the USAF [3] in 1973, whereby only the initial part of a ground pulse is examined. In order to understand this much more accurate location approach we need to also understand the physical process of a lightning ground stroke.

2.0 THE LIGHTNING PROCESS IN A CLOUD-TO-GROUND DISCHARGE

A cloud-to-ground lightning discharge is made up of one or more intermittent partial discharges. The total discharge, whose time duration is of the order of 0.5 seconds, is called a flash; each component discharge, whose luminous phase is measured in tenths of milliseconds, is called a stroke. There are usually three or four strokes per flash, the strokes being separated by tens of milliseconds. Often lightning as observed by the eye appears to flicker. In these cases the eye distinguishes the individual strokes which make up a flash. Each lightning stroke begins with a weakly luminous predischarge, the leader process, which propagates from cloud-to-ground and which is followed immediately by a very luminous return stroke which propagates from ground-to-cloud.

It has been found that the electrostatic field takes ahout 7 seconds to recover to its predischarge value after the occurrence of a lightning flash at a distance beyond 5 km, but when the flash is very near, the recovery time may be different due to the presence of space charge. In both cases, regeneration of the field takes place exponentially.

2.1 Stepped Leader

The usual cloud-to-ground discharge probably begins as a local discharge between the p-charge region in the cloud base and the N-charge region above it (Figure 2). This discharge frees electrons in the N-region previously immobilized by attachment to water or ice particles. The free electrons overrun the p-region, neutralizing its small positive charge, and then continue their trip toward ground, which takes about 20 msec. The vehicle for moving the negative charge to earth is the stepped leader which moves from cloud-to-ground in rapid luminous steps about 50 m long, as shown in Figure 2. Each leader step occurs in less than a microsecond, and the time between steps is about 50 μ sec.

2.2 Return Stroke

When the stepped leader is near ground, its relatively large negative

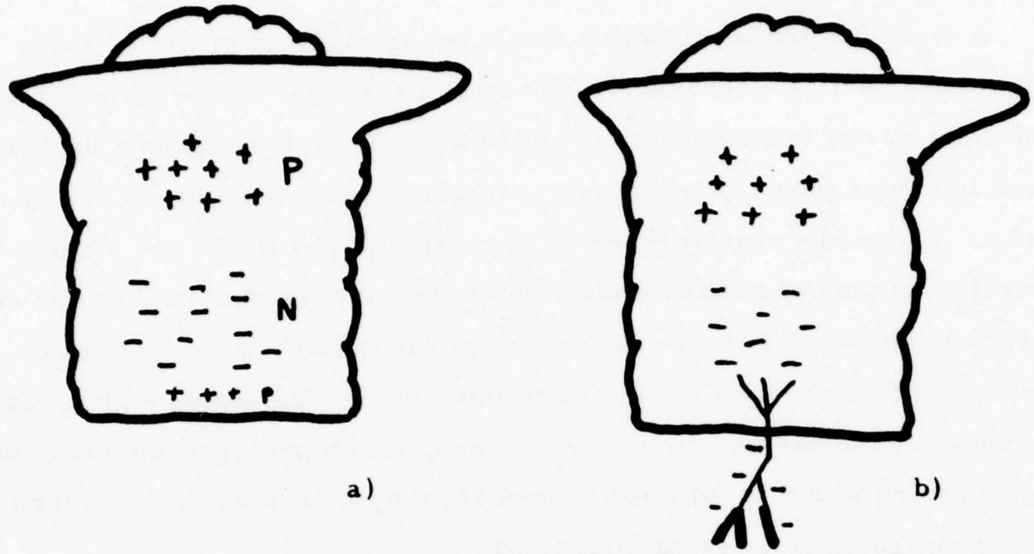


Fig. 2 Stepped leader initiation; a) cloud charge prior to p-N discharge, b) stepped leader moving downward in 50 m steps.

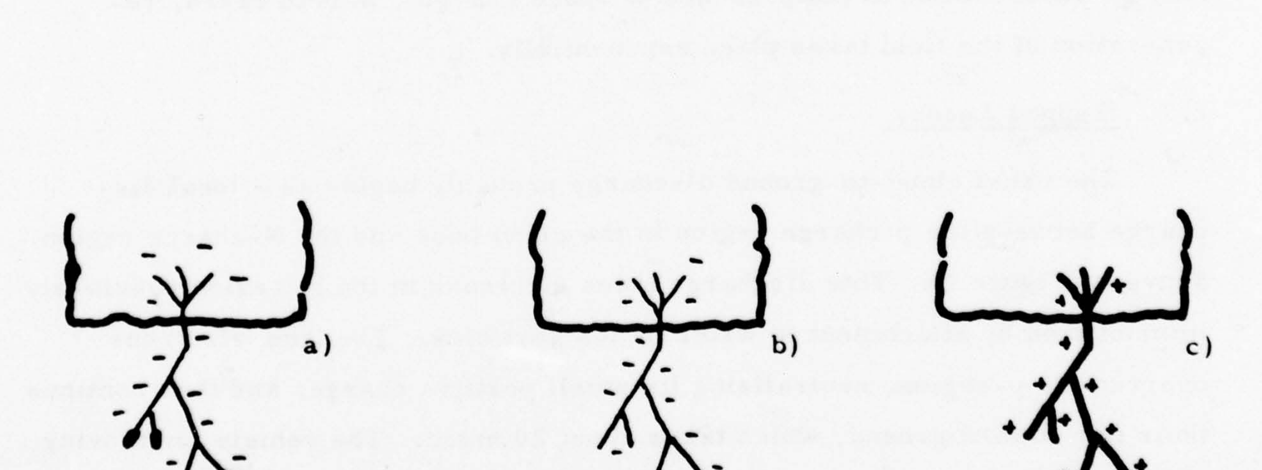


Fig. 3 Return stroke initiation; a) start of upward moving sparks to meet leader; b & c) return stroke propagation from ground to cloud.

charge induces large amounts of positive charge on the earth beneath it and especially on objects projecting above the earth's surface (Figure 3). Since opposite charges attract each other, the large positive charge attempts to join the large negative charge, and in doing so initiates upward-going discharges. One of these upward-going discharges contacts the downward-moving leader and thereby determines the lightning strike point. When the leader is attached to ground, negative charges at the bottom of the channel move violently to ground causing large currents to flow at ground and causing the channel near ground to become very luminous. The channel luminosity propagates continuously up the channel and to the channel branches at a velocity somewhere between 1/2 and 1/10 the speed of light. The trip between ground and cloud takes about 100 μ sec. When the leader initially touches ground, electrons flow to ground from the channel base and as the return stroke moves upward, large numbers of electrons flow at greater and greater heights. Electrons at all points in the channel always move downward, even though the region of high current and high luminosity moves upward.

It is the return stroke that produces the bright visible channel. The eye is not fast enough to resolve the propagation of the return stroke, or the stepped leader preceding it, and it seems as if all points on the channel become bright simultaneously.

After the first return stroke is complete, more charge may be made available to the top of the ionized channel and a dart leader will then pass down this branchless channel to ground, once more depositing negative charge. A second return stroke then passes up the channel. The process may continue several times in a fraction of a second.

2.3 Intracloud Discharge

Intracloud discharges have a duration of the order of 0.2 seconds, causing a continuous low luminosity in the cloud. It is thought that during this time a propagating leader bridges the gap between the two main charge centers. Superposed on the continuous luminosity are relatively bright luminous pulses

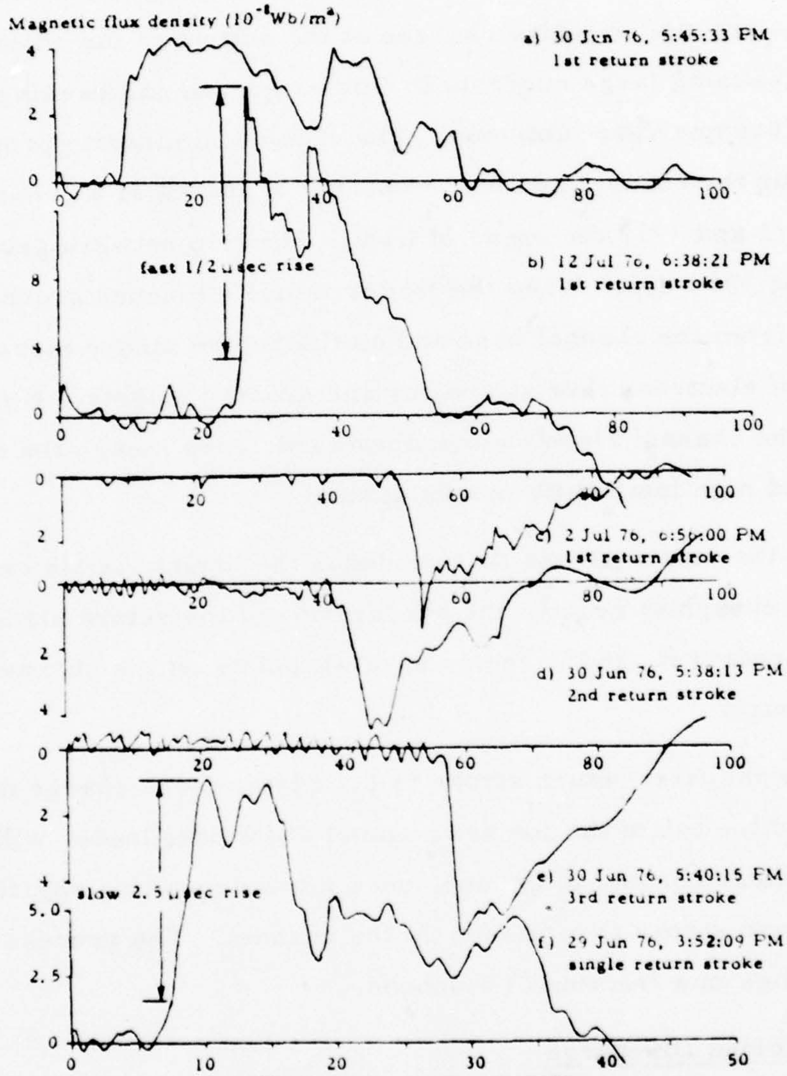


Fig. 4 Magnetic field return stroke waveforms preceded by stepped leader and dart leader pulses showing typical fast rises and less common slow rises.

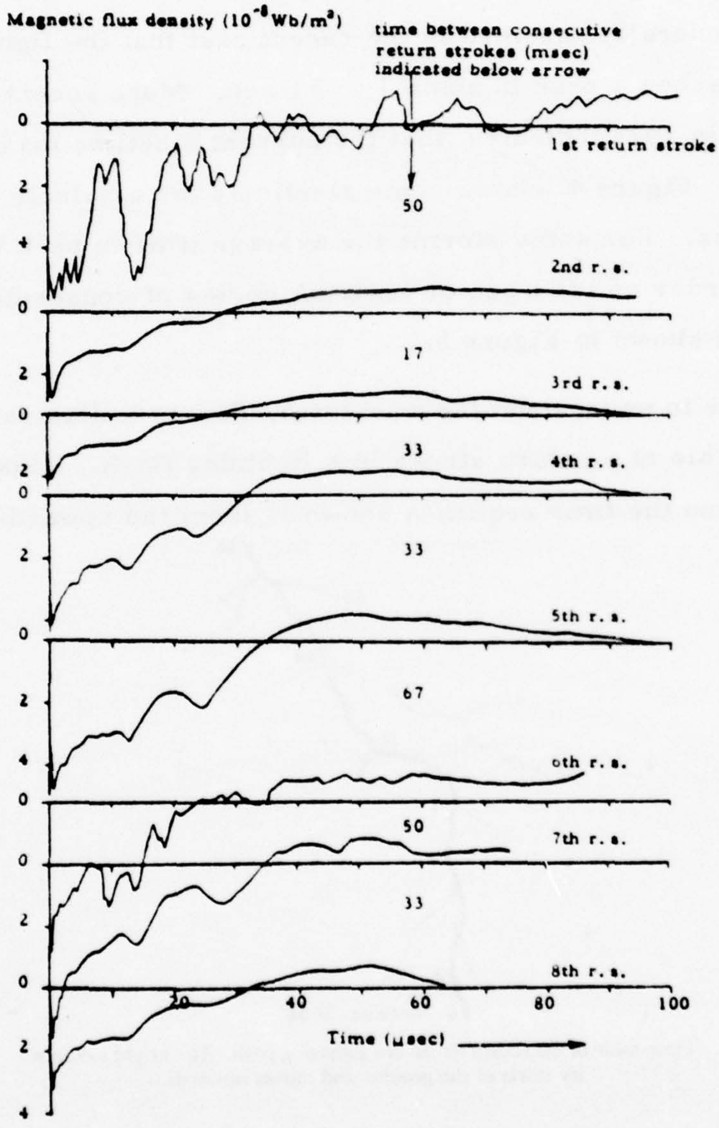


Fig. 5 Eight consecutive return strokes of a close flash on 2 Jul 76 at 6:50:10 PM. The 6th trace may be the return stroke to a dart-stepped leader.

which are probably relatively weak return strokes that occur when the propagating leader contacts a pocket of charge of opposite polarity to that of the leader. Direction finding on such waveforms can not be achieved by broadband magnetic field techniques.

2.4 Magnetic Field Waveform

A significant characteristic is the rate of rise of the current waveform. It has been generally assumed in the recent past that the lightning current waveform reaches a peak in some 1 to 3 μ sec. More recent information by Llewellyn[4] in 1977 indicates that the current risetime may be much less than 1 μ sec. Figure 4 shows some risetimes for a selection of close and distant storms. For some storms the average time to peak value was found to be of the order of 1/4 μ sec or less. A series of consecutive return stroke waveforms is shown in Figure 5.

In order to understand the waveform, Figure 6 illustrates the approximate time table of a return stroke in a lightning flash. This was photographed by Malan[5], and the time sequence shown is from the upward-moving bright luminosity.

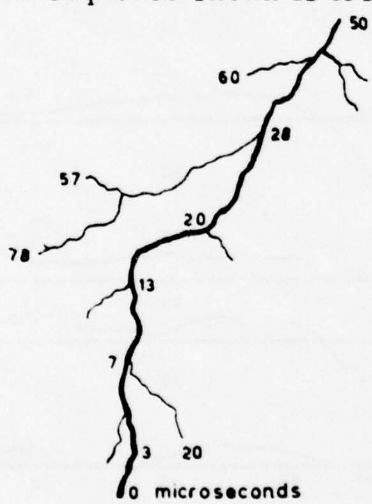


Fig. 6 Time-table of the return stroke of a lightning flash. The bright luminosity starts at the ground and moves upwards.

It is seen from Figure 6 that a receiver bandwidth capable of monitoring time periods of 1 μ sec or faster (1 MHz or broader) would, in this case, be able to detect signatures from the base of the return stroke, whereas a lower

frequency would monitor possible signatures from higher branches and bends leading to the large errors shown in Figure 1. This principle of gating a broadband receiver to detect only the base of the return stroke forms one of the basic ideas behind the lightning position and tracking system.

3.0 LIGHTNING POSITION AND TRACKING SYSTEM (LPATS)

The recent advancements in monitoring and understanding the magnetic field characteristics from lightning that have just been discussed have led to the capability of accurately detecting and tracking lightning at close ranges (1-400 km). The Lightning Positiion and Tracking System (LPATS) relies on being able to detect the cloud to ground discharge by its unique broadband magnetic field waveform. Once detected this waveform is sampled for the part of the return stroke that is within 100 feet of the ground. It is well known that this part of the discharge is almost always vertical and carries the greatest energy, implying that we have a vertical omni-directional radiating antenna and a powerful transmitter. LPATS detects the characteristics of the return stroke, sampling several parts of the waveform, and in particular it samples the peak value which occurs during the first 100 feet or so.

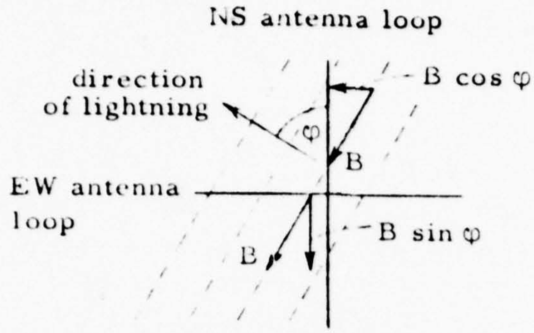
For ideal monitoring three receiving stations are set up at points comparable to the vertices of an equilateral triangle, with base line about 1/4 of the distance to be covered. Each station has a pair of orthogonal loop antennas and a receiver. The station will need virtually no maintenance and is easy to set up. The data collected will be transmitted via telephone line (or VHF/UHF link) to a central station which monitors the signals and computes the desired information. The results can be displayed in map form on a video terminal, displayed on a printer or input to a computer.

The units perform well in locating lightning from 0 to 400 or more kilometers because lightning energy is enormous. When a signal above a threshold level is detected its characteristics are transmitted within milliseconds to the master station. Analysis is performed on the data arriving on the three incoming lines and triangulation calculations show the point of the strike. This is repeated for each return stroke. If the characteristics are such that it is not a return stroke, the lightning signals received must be from an intracloud discharge, and pertinent cloud stroke information can be recorded.

The advantages of LPATS are its low cost,ease of installation and maintainance, and its accuracy. LPATS also has the ability to allow many parameters to be monitored such as lightning intensity, speed and direction of movement, and display information on a video screen map or incorporate it into any computer system.

4.0 SYSTEM DESCRIPTION

4.1 Single Discharge Directional Location



Two Orthogonal Loop Antennas

Two orthogonal loop antennas and their related broadband receivers (lkHz to 100 MHz) monitor the magnetic field from a lightning stroke. When the stroke is vertical, close to the ground, the signal received in the North-South antenna is proportional to B cos φ; whereas the East-West received signal is proportional to B sin φ. The microcomputer determines the part of the signal from the region close to the ground and computes the angle to the discharge by simple trigonometry. The information sent to the computer includes the waveform characteristics, such as time-to-peak and half peak, as well as peak value.

4.2 Distance Computation

Three such sites send similar information on the discharge to the computer, which immediately calculates the angle from each site and determines the point of contact by triangulation. As a result, the distance of the discharge from the center of interest is known along with the azimuth angle.

4.3 Angular and Distance Accuracy

Tests on the angular accuracy from a single station to a lightning strike have been carried out over Central Florida during the last year. Monitoring of close lightning (8 miles) was carried out by video photography, and distant storms were monitored by high resolution infrared satellite cloud photography.

The angular data from the single station LPATS agreed to the angular resolution of the video system which is about $\pm 1^\circ$. Monitoring of the distant cells indicated that similar accuracies existed. Using simple triangulation trigonometry, this 1° error can be extrapolated to two dimensional errors in a three station system. These errors have been calculated by a computer for a 10 mile baseline using two of the three stations and are shown in Figure 7. These errors will satistically improve as the storm progresses and more data becomes available.

4.4 Differentiation between Intracloud and Ground Strokes and Probable Tornado Detection

In the software,intracloud and ground strokes can be easily differentiated by their waveform characteristics, since the values for signal peak amplitude and rise and decay times differ significantly. Actual recordings of return stroke magnetic waveforms were shown in Figures 4 and 5. Tornado monitoring is also possible by monitoring bursts of HF signatures as reported by Taylor[6]. This burst information can be displayed on the video terminal.

4.5 Determination of Storm Parameters

We have shown that LPATS is capable of almost instantaneous recording of lightning flash position. With competent software development it is possible to generate programs to supply storm location, direction of movemert, intensity, and other relevant facts. The exact calculation and information display can, of course, be modified to suite the user's needs, but the following techniques have been incorporated in present systems.

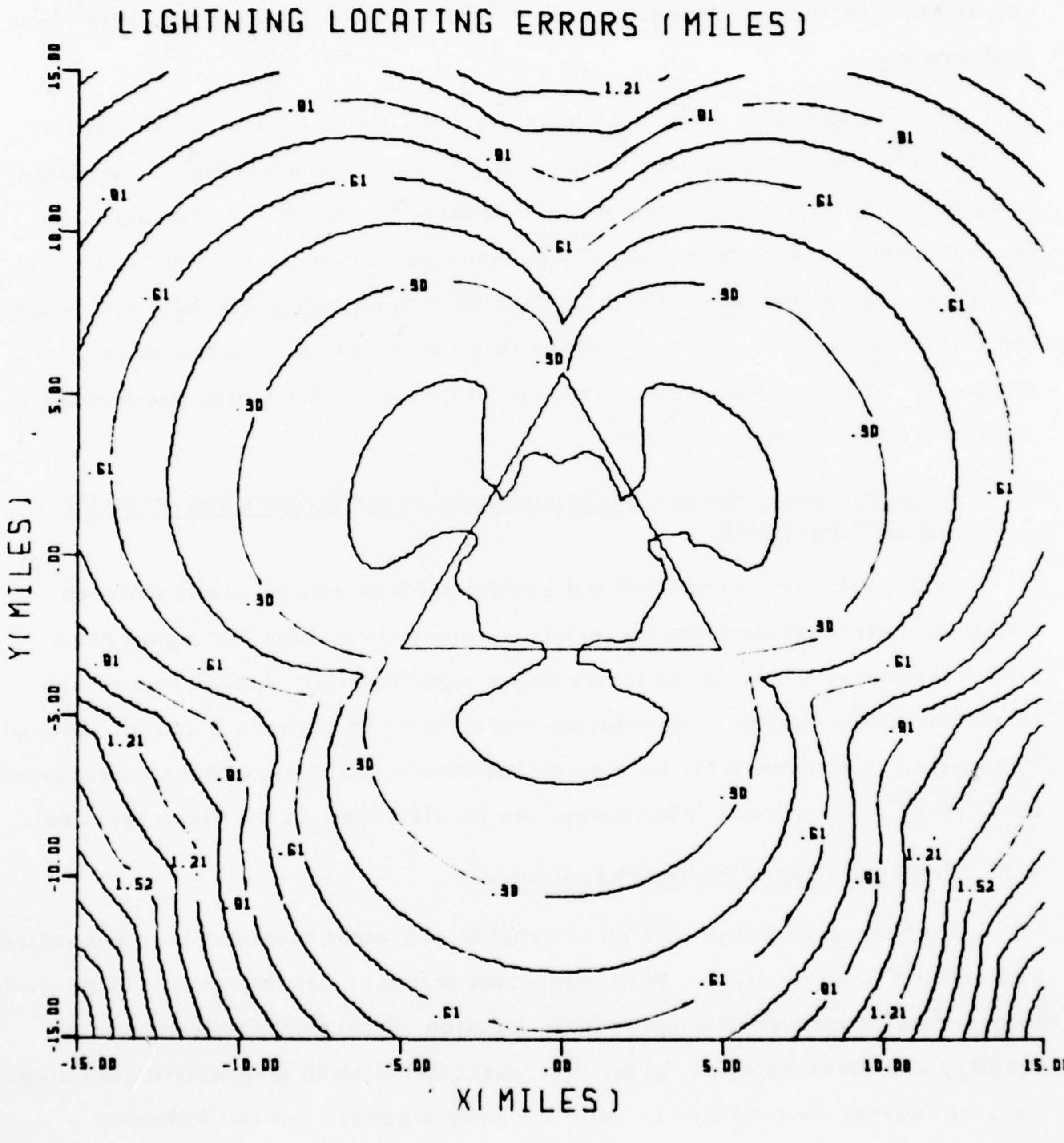


Fig. 7 LPATS Locating Errors for a System on a 10 Mile Baseline.

4.6 Single and Multiple Storm Cell Resolution

The computer has in its memory the exact strike positions for the last several minutes. Software can be written to accept each cluster of points, over a particular distance and time, which will correspond to a cell. The center of gravity of each cluster can be computed as the storm center. By these means, all the existing cells can be monitored and separately identified. The information from each antenna location is received and processed within milliseconds such that the individual return strokes in a flash can be monitored for greater accuracy. The likelihood of two different discharges occurring within a few milliseconds is very remote. Such discharges would probably be triggered from the same cell and the different strokes will probably be more than 100 msec apart. Once the return stroke has hit the ground the signal moves at the velocity of light or 186 miles per millisecond, which again illustrates the rare chance of two discharges interfering with location accuracies.

4.7 Storm Intensity

Because information from storms is fed into the microcomputer memory within milliseconds and because the computer has already defined the different cells, there should be no problem in resolving the intensity of each one of several storms. This intensity could be defined as either electric current intensity or flash rate, or both. The recorded intensity of the signal from each site allows the current in the discharges to be monitored with reasonable accuracy, and the number of discharges per cell occurring within each minute can be counted to determine the flash rate. This data can be displayed in number code on a display.

4.8 Speed and Direction of Storm Movement

Monitoring the change in position of the center of gravity of each storm cell and relating it to the corresponding time interval, will identify the speed and direction of movement. This information could be illustrated on a display

with arrows and numbers, or it could be fed into an existing computer in any desired way. The experience of each user will define his ideal requirements which could be changed by simple software modifications.

4.9 Auto, Calibrate and Self Check Capability

The remote systems have the capability of self checking the analogue to digital converter at the system voltage levels and also the receiver and attenuator sections for fault diagnostic purposes. The system is also designed to allow processor and memory checks to be carried out at the remote sites under direction from the central processor. Any faults uncovered by these means are listed at the CPU.

An update capability allows a user to update from the CPU the remote system's internal waveform analysis selector, attenuator settings, delay time requirements and cloud or ground stroke information.

4.10 Electric Field Monitoring

The LPATS computer is capable of receiving data from field mills placed at selected sites so that warning of an impending first stroke from a thundercloud can be displayed on the terminal.

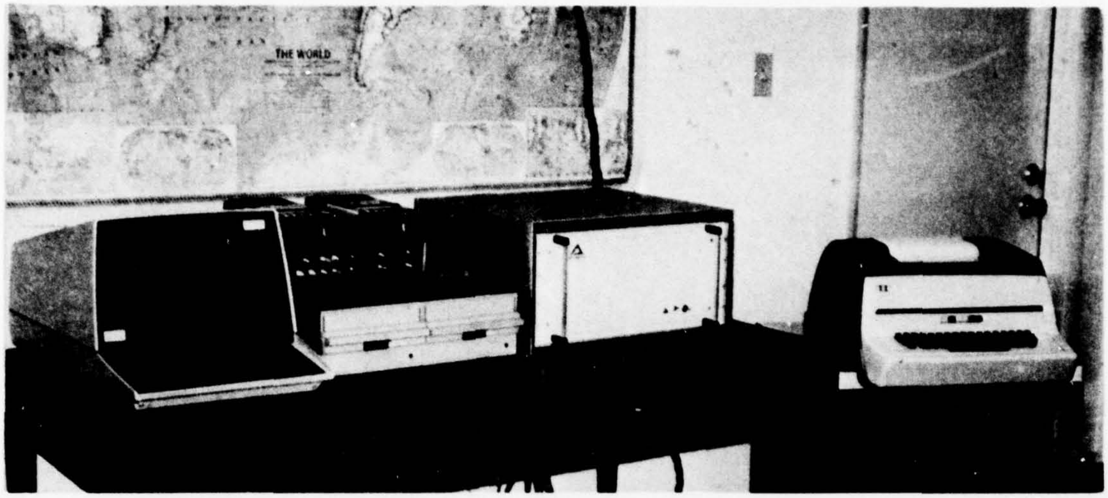


Fig. 8 LPATS Receiver, Display, Disc & Tape Recorders & Teletype.

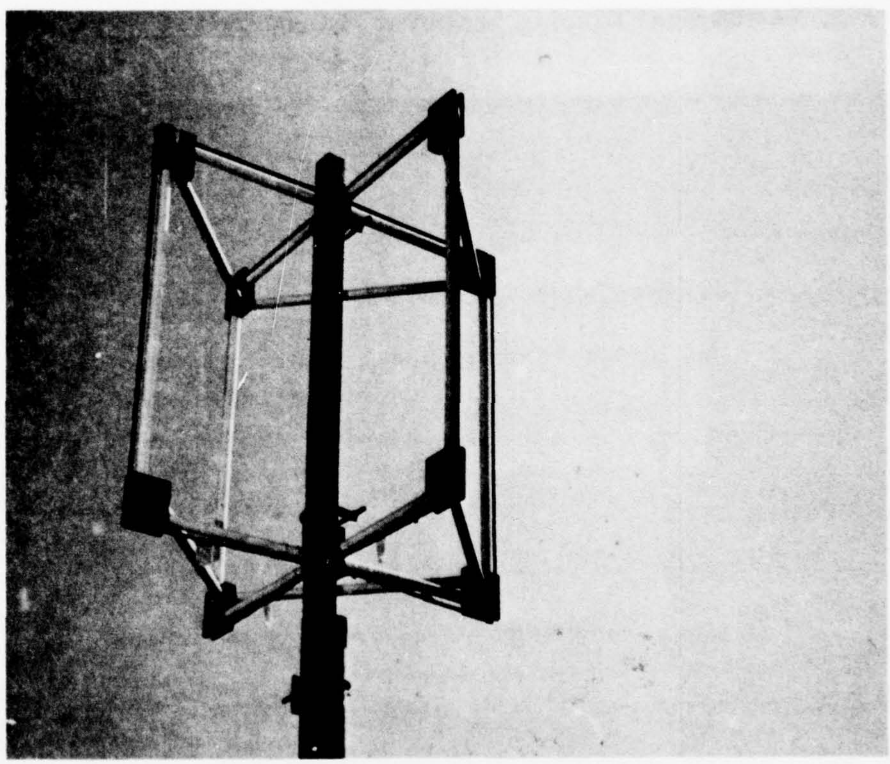


Fig. 9 Typical LPATS Antenna.

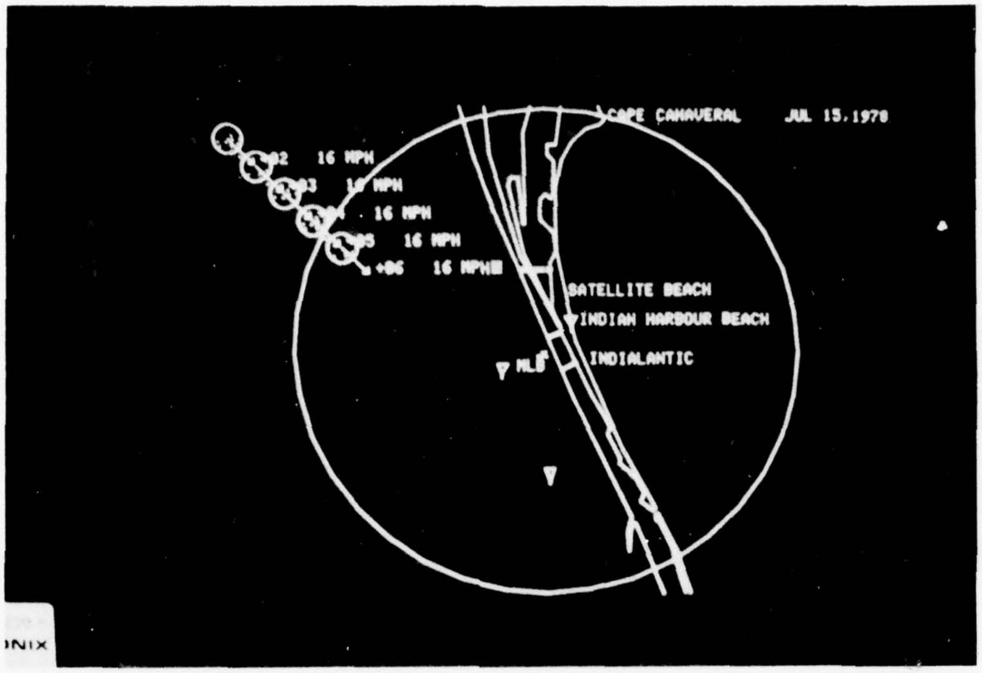


Fig. 10 Typical Display of Storm Moving Towards Melbourne Airport.

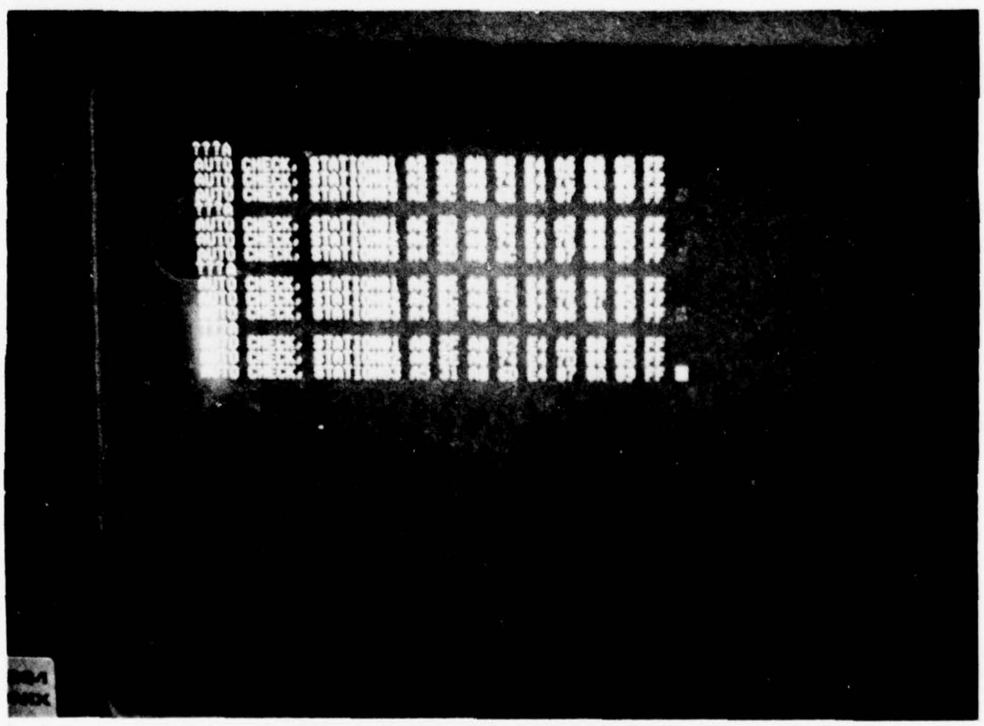


Fig. 11 System Auto Check Capability.

5.0 RESULTS

The LPATS system is shown in Figure 8. A basic system would incorporate the video terminal and the 19" x 8" electronic unit. The photograph shows these two with the addition of magnetic tape recorders, disc recording and teleprinter output. The crossed-loop antennas are shown in Figure 9.

A video display showing a storm approaching Melbourne airport at 16 mph is shown in Figure 10. The strike positions are shown along with storm intensity. During non-active days, an auto check is possible in order to investigate the correct functioning of each system. Such a display is shown in Figure 11.

A single station system is being developed where accurate angles to the discharge are recorded, and distance is obtained from the relationship between electrostatic and magnetic fields radiated from the lightning discharge.

Figure 12 shows data from each of three remote sites for several return strokes in four different flashes. It is interesting to note the return stroke risetimes that vary from 0.2 to 1.8 μ sec. The discrepancy between first and subsequent return stroke angles is probably due to low level branching in the first return stroke. More accuracy is, therefore, achieved by using the subsequent data for positional information. This risetime information is extremely useful research data for understanding the basic problems in surge protection and lightning protection.

STN.	TIME	NS (V)	EW (V)	AZ (DEG)	TTP (US)	TTP/2 (US)
01	06 17 18	-6.84-01	-1.03+00	+1.23+02	+3.00-01	+4.40+00
		-9.00-01	-1.66+00	+1.18+02	+4.00-01	+3.60+00
		-7.43-01	-1.35+00	+1.18+02	+3.00-01	+9.20+00
02		-3.71-01	-5.87-01	+1.22+02	+2.00-01	+5.00+00
		-4.30-01	-5.87-01	+1.26+02	+3.00-01	+3.60+00
		-4.10-01	-5.47-01	+1.26+02	+2.00-01	+1.08+01
03		-5.47-01	-1.36+00	+1.11+02	+2.00-01	+4.80+00
01	06 18 12	-9.58-01	-1.70+00	+1.19+02	+7.00-01	+4.40+00
		-7.82-01	-1.23+00	+1.22+02	+2.00-01	+4.00+00
02		-4.10-01	-5.08-01	+1.28+02	+2.00-01	+4.80+00
03		-5.28-01	-1.78+00	+1.06+02	+5.00-01	+4.00+00
01	04 34 59	-3.13+00	-8.61-01	+1.64+02	+8.00-01	+2.80+00
		-4.28+00	-1.19+00	+1.64+02	+1.10+00	+3.60+00
		-2.73+00	-7.82-01	+1.64+02	+7.00-01	+2.80+00
02		-9. -01	-1.17+00	+1.28+02	+8.00-01	+3.26+00
		-3.22+00	-3.40+00	+1.33+02	+1.00+00	+3.60+00
		-6.45-01	-6.45-01	+1.33+02	+8.00-01	+3.20+00
01	01 02 12	-4.89-01	-1.42+00	+1.08+02	+4.00-01	+3.20+00
		-5.08-01	-1.25+00	+1.12+02	+2.00-01	+3.60+00
02		-2.34-01	-7.04-01	+1.08+02	+2.00-01	+3.20+00
03		-3.32-01	-1.36+00	+1.03+02	+1.80+00	+1.12+01
		-4.10-01	-1.36+00	+1.06+02	+2.00-01	+3.60+00

Fig. 12 Typical teleprinter output of individual return stroke characteristics as monitored from three sites for four different strokes. January 23, 1979.

REFERENCES

1. C. V. Ockenden, "Sferics," Meteorol. Mag., Vol. 76, pp. 78-86 (1947).

2. R. C. Noggle, E. P. Krider, and M. A. Uman, "A Lightning Location System Based on Magnetic Radiation Field Peaks," EOS, Vol. 54, p. 1100 (1973).

3. USAF, TR 74-043, "Lightning Detection and Location," (1973).

4. Llewellyn, S. K., 1977, "Broadband Magnetic Waveforms Radiated from Lightning," FIT (1977).

5. Malan, D. J., 1963, "Physics of Lightning," English University Press Ltd.

6. Taylor, W. L., "Detecting Tornadic Storms by the Burst Rate Nature of EM Signals They Produce," *American Meteorol. Soc.*,(1975).

DESIGN, DEVELOPMENT AND FABRICATION OF DEVICES FOR THE PROTECTION OF ELECTRONIC EQUIPMENT AGAINST LIGHTNING

Jean-Pierre Simi

Les Cables de Lyon
Telecommunications Department - H. F. Division
65 Rue Jean Jaures
95871 Bezons, France

BIOGRAPHY

J. P. Simi is Product Engineer for design and application of devices for the protection of electronic equipments, against EMP and lightning. He began his higher studies in the Faculty of Sciences of Paris in 1962 where he received his MPC degree and a General Chemistry certificate. In 1965, he joined the French School of Radioelectricity, Electronic and Informatic and received his E.F.R. degree in 1968. He began overlevel studies through cables in 1967 and was responsible during 6 years (1971 to 1976) for the experiments with the French Department of Defense (S.T.T.A.) in the Nuclear Experiment Center of the Pacific. Since 1975 his job has been involved in the design and application of protection devices against lightning (especially for French Civil Aviation - S.T.N.A.) and the EMP (high and low altitude) for the French D.O.D.

INTRODUCTION

Recently, the problem of electronic equipment protection has become more and more important.

The main reasons are:

Increasing density of electronics. This is due to ever increasing chip density, allowing greater packing of elementary components.

Normal circuit operating voltages have dropped from hundreds of volts to several volts so that ratio of over to normal voltage has been increased perhaps by one hundred.

At the same time, electronic equipment became more and more sophisticated, requiring more and more elements and connecting cables.

Finally, we must consider that we require more and more confidence in electronic systems. So they must remain quite reliable even when surges occur.

For these reasons it seems to be normal that lightning, EMP and other overlevels of protection are becoming a fundamental concern of modern engineering.

PREAMBLE

Any equipment is generally quite satisfactory when used in a laboratory.

If you encounter some problems during normal use, it is because the environment in which it is now used is no longer the same.

So, when you have to solve any equiment protection problem, you have to consider this environment, and in particular:

- The building or shelter in which the equipment is used
- The earth and ground connections
- The proximity of other materials, which can represent a further source of disturbance
- Power lines to the equipment
- Long signal lines to the equipment.

We will deal rapidly here with the last three points, but with emphasis on the power and signal protection devices, and in those emphasize coaxial protection devices.

THE TECHNICAL BUILDING

The best technical building you can imagine is in fact a Faraday's Cage, connected to a good ground reference.

However, you know that you can never get it for several reasons.

So everything you do which makes your technical building look like a shielded room will be in the right direction.

For example, you will have to:

- Weld all the reinforcing bar crossing points when the wall are built.
- Install under the future building a good earth reference, made of an iron network which will be extended further than the building limits
- Connect all the building metallic pieces and all the equipment to this ground reference

From the point of view of lightning protection, such an insulated building or an assembly of buildings grouped together will be considered as a single unit and referenced to the same ground. We will call this an "insulated unit" as compared with other external buildings which, due to the strength of the surges expected will be dynamically referenced to a different level when a surge occurs on one of them.

When you consider such an "insulated unit" you have only two ways of entrance of the surges. These are:

- Horizontal lines (power and signal lines)
- Vertical lines (antenna feeders for example).

The object of the protection devices we will speak about is to limit to a non-destructive value the surge levels which will reach the equipment installed in the unit.

Note that the resulting levels will come from:

The lightning current on wires (we eliminate the strong lightning currents directly fall-ing on the equipment, which are supposed to follow first the lightning down conductor)

The circulation current due to the different potentials taken at the same time by the different "insulated units".

Further, when the devices are installed, you may have to further protect some extra sensetive equipment by putting protective devices directly on the individual circuit cards.

The protection devices described here must only be put on the external connections of the equipment with the other units (signal and power lines) and on the antenna feeders.

DEVICES FOR THE PROTECTION OF POWER LINES

Devices for the protection of power lines must be studied regarding two main characteristics:

- the normal operating level (HV, MV, LV)
- the distributed power in the line

The protection of high and medium voltage power lines

Generally they are distributed in delta configuration, three wires. The only protection which gives results consists in applying the appropriate voltage arresters. So, we can get the arrangement shown in figure 1.

Regarding the power in the line, and in order to avoid upstream effects, you must choose an arrester which is specially developed for power applications. In fact it generally combines a spark gap and a series VDR which warrant the arc extinction. You can see also that the resulting surge is high all the same, so it will be necessary to provide further protection (generally this protection is made on the low voltage line, where the sensitive equipment is connected). Figure 2 is a example of such a protection device (HV 6kV and MV 900V).

Protection of the low voltage lines

Low voltage lines can be distributed in delta or wye configuration.

For protection here, you can use low voltage arresters. They will conduct the main energy of the overvoltage to ground.

An example of such a device is shown in figure 3. We can call it "primary protection", because it is generally not efficient enough regarding the sensitive equipment connected downstream; because of its delay of response, road surges will remain.

So you have to complete it with a rapid response component. It may be obtained, for example, from a TransZorb (R) and a AC power filter. If you want a good efficiency of the arrester plus TransZorb association you have to introduce a delay between the two components. In the example in figure 4 this delay is obtained by using a 100 uHenrys 15 amperes inductor.

In figure 5 you can see the dynamic response of such a protection regarding a 20 kV pulse.

The effects (with a resistive load of 12 ohms) are shown on:

- the arrestor alone
- the arrester and the TransZorb (R)
- the complete device.

In figure 6 you can see two devices.

- a one-wire 3KvA low voltage protection.
- a three-wire 9 kVA LV protection.

If you need decoupling protection, you can avoid common mode surges by using a transformer. Such a arrangement is shown in figure 7. You can see that there is no need for the inductance because of the self-impedance of the transformer itself.

DEVICES FOR THE PROTECTION OF SIGNAL LINES

Because of the small cross-section of the elementary wires in such a cable, we can expect only limited power surges on it. That is why such protection devices will be built from smaller simple components, which can be placed on print-ed circuit cards.

Basic diagrams are built with arresters (small 200 V spark gaps), selfs (some hundred microhenrys) and transient surge devices (for example TransZorbs (R) of the IN 56 . . A JANTX series). There are also other components such as fuses and resistors (resistors must be put in order to guarantee arc extinction in the spark gap when the device is installed to protect a line which has for example a permanent DC voltage with respect to the ground.

Of course, the final circuits must take into account the signal itself and in fact:

- its polarity (which can be positive, negative or both
- its peak level (DC, AC or both DC and AC)
- whether or not you have to transmit DC levels
- the highest frequency that you have to transmit (or the rise time of digital signals)

The series devices we have built are identified both through a color and a number. The color may be:

yellow for positive signals
red for negative signals
blue for bipolar aignals
green for AC signals only

The number can be from;

01 to 49 for low frequency devices
50 to 99 for low capacitance devices.

Because of the gap chosen (CASR type from Claude) you can conduct to ground a 5 KA/30 us current.

The residual surge level is identified by the TransZorb (R) number, as you can see in figure 8.

It shows a 2kV - 3/20 us surge through a "Red 04" device (which is mounted with a IN5653A JANTX TransZorb (R)).

Figure 9 shows two other examples of such devices (a "Yellow 02" and a "Blue 09").

Note: to remain efficient, you have to put such devices on each wire of signal cables. So you rapidly need an significant quantity of them. Figures 10 and 11 show examples of such installations, taken in Berlin-Tegel airport, where about seven thousand were installed for ligthning protection.

DEVICES FOR THE PROTECTION OF COAXIAL LINES

On a coaxial line you will generally find:

- video signals (from low frequencies to some 10 megaHertz)
- high frequency signals (antennas and so on).

For the protection of video signals you can realize protection devices derived from low frequency signal protections described previously.

For high frequency protection devices you must use the technique of tuned lines, which will provide very efficient static protections.

Protection of a TV video signal

The diagram of such a protection is shown in figure 12 (top). You can see that it is a decoupling system. The coaxial transformer used here is a 75/75 ohms impedance device. Its pass band covers 20 Hz to 9MHz at less than 2 decibles (figure 12 bottom).

It is protected upstream by sparkgaps (you can see that the external coaxial line which is supposed to be the means of entrance of the lightning current is now insulated from the shelter and from the equipment). Downstream you can see a coaxial TransZorb (R) TPD series (reference G770210 followed by A for 5 volts and B for 24 volts).

Such protection is very efficient and you can see a test result in figure 13.

Note: When you have put such a decoupling device at each end of a long line (coaxial here) you must not let it without dc reference to the ground because it will collect all the ground circulation currents and you will get some disturbances. In figure 14 we have shown two ground connections which avoid this, and allow, in addition, primary protection against lightning effects, because only a small part of the lightning current will reach the protection (because of the greater dc impedance of the protection, seen from the external cable, largely insulated).

Devices for the protection of high frequency coaxial lines

When the signal is high frequency (or very high or ultra high, or more) you have to use the tuned lines technique. It consits in making use of the properties of the quarter-wavelength lines.

From this technique you will be able to realize two kinds of protection devices, which are: (see figure 15)

- Decoupling devices. It introduces on the line a high series impedance for dc current (or generally for low frequency current, regarding the high frequency normal signal in the line). See figure 15B.

- Tee of protection. It presents a low impedance path to the ground for the dc currents (or more generally for the low frequencies, but not effecting the high frequency normal signal in the coaxial line). See figure 15A.

- The combination gives a very good and compact protection device. See figure 15C.

Of course, such protection devices must be built and tuned regarding:

- the impedance of the coaxial line to be protected

- the bandwidth of the high frequency signal

- the VSWR and the insertion loss permitted

- the protection required for lightning frequencies

Figure 16 shows 12 examples of the main technical data of some of the devices built since 1972.

You can see in figures 17 and 18 such devices as used in a frequency transmitter station which is equipped with these coaxial protection devices on each feeder. (Berlin 1976).

CONCLUSION

In order to realize efficient protection of any electronic equipment, you must:

- consider its total environment

- take account of all its lines, including power, signal and antenna lines

- install the specific protection device on each wire which is directly connected to the equipment

- do not forget any wire.

When you have done this, and except for the strong lightning surges which could directly hit the equipment itself, you can consider its protection against all main surges ensured.

PROTECTION MT ou HT PAR PARFOUDRES

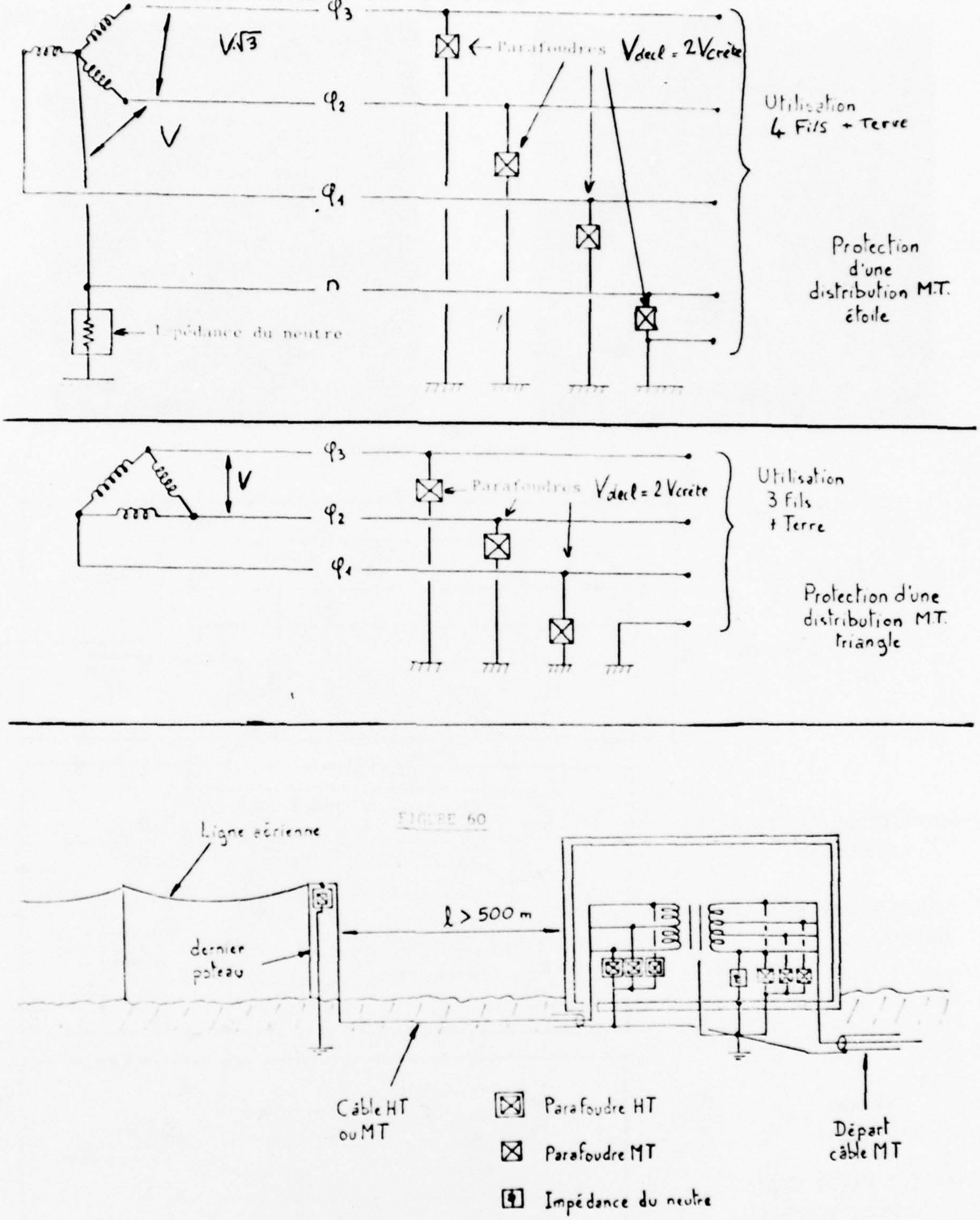


Figure 1 PRIMARY HV OR MV PROTECTION

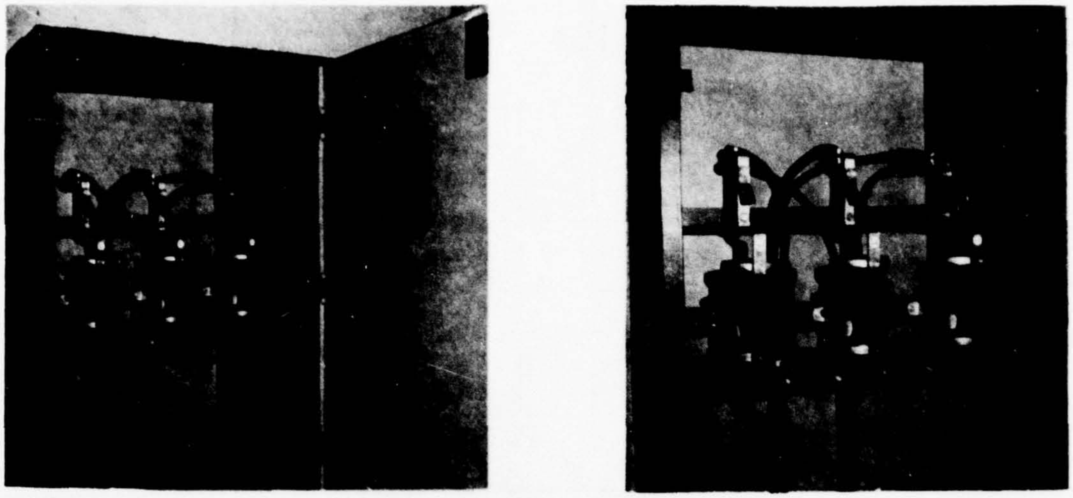
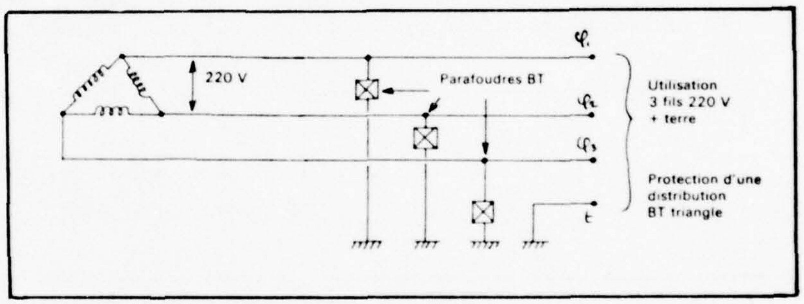


Figure 2 HV 6 KV PRIMARY PROTECTION

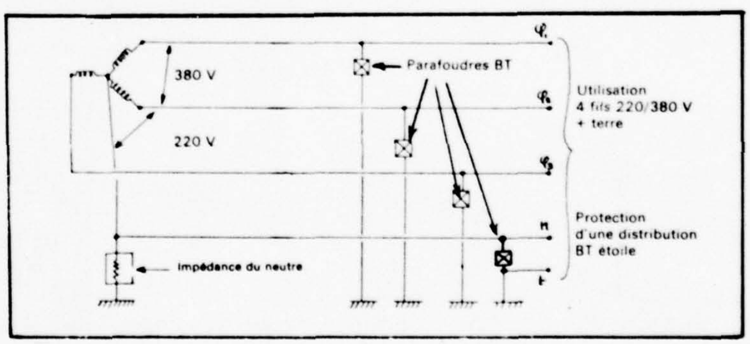
DISPOSITION
TRIANGLE

(DELTA 3 WIRES)



DISPOSITION ETOILE AVEC
N IMPEDANT

(WYE 3 WIRES WITH IMPEDANT
NEUTRAL)



ETOILE
N à TERRE

(WYE 3 WIRES VITH
GROUNDED NEUTRAL)

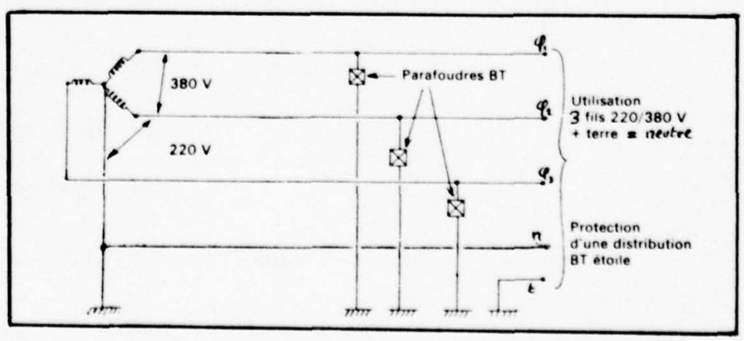
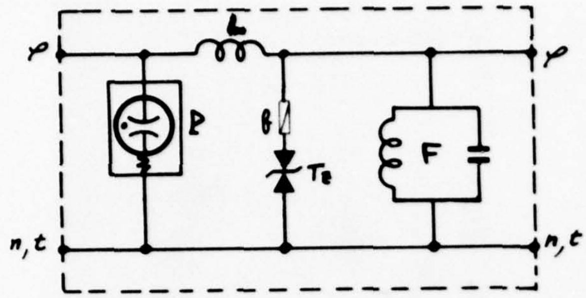
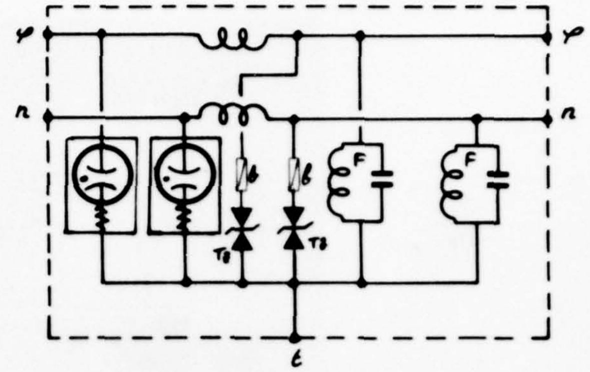


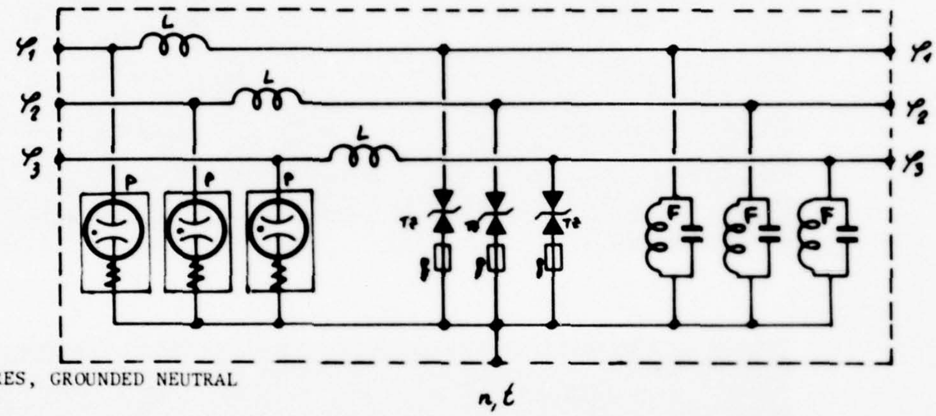
Figure 3 PRIMARY LOW POWER PROTECTION



1 WIRE, GROUNDED NEUTRAL



1 WIRE, IMPEDANT NEUTRAL



3 WIRES, GROUNDED NEUTRAL

Figure 4 COMPLETE LV PROTECTION

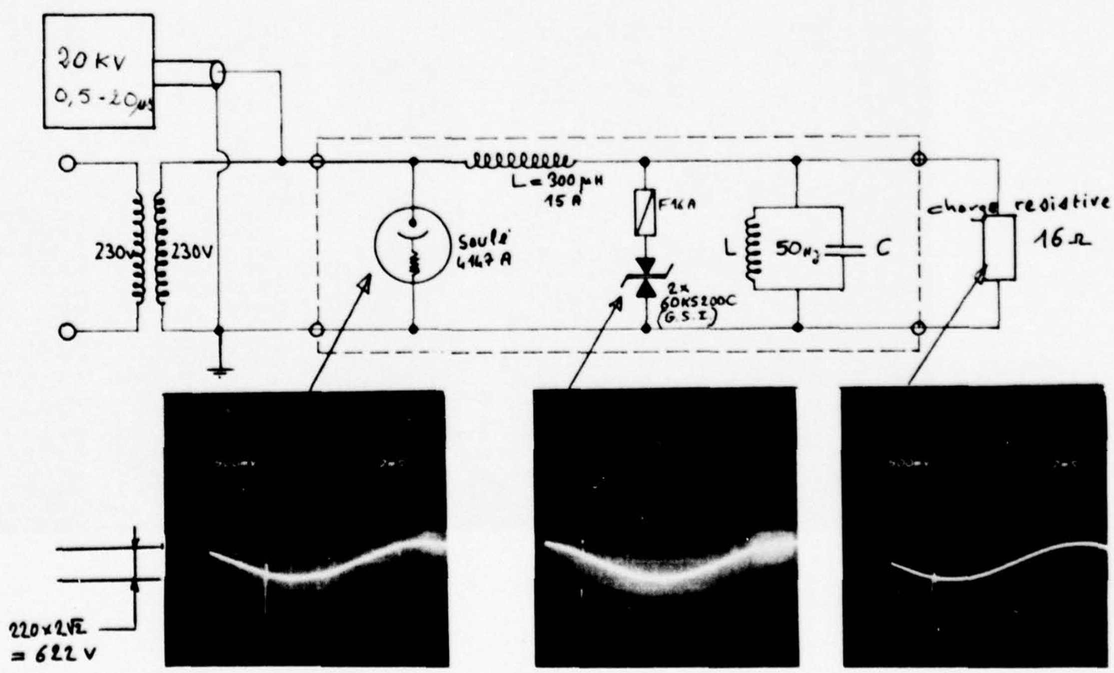
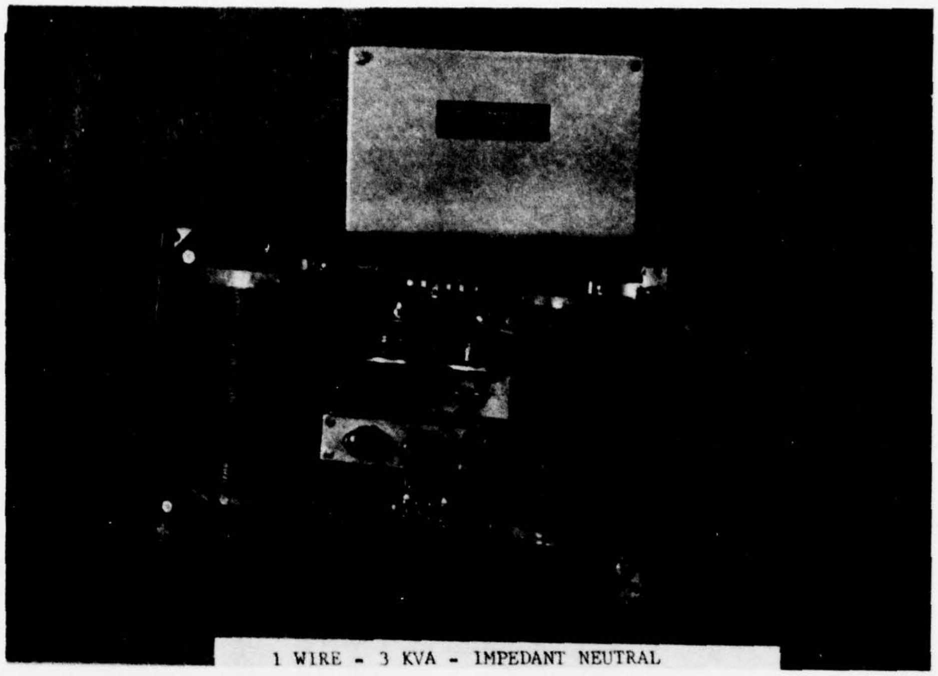
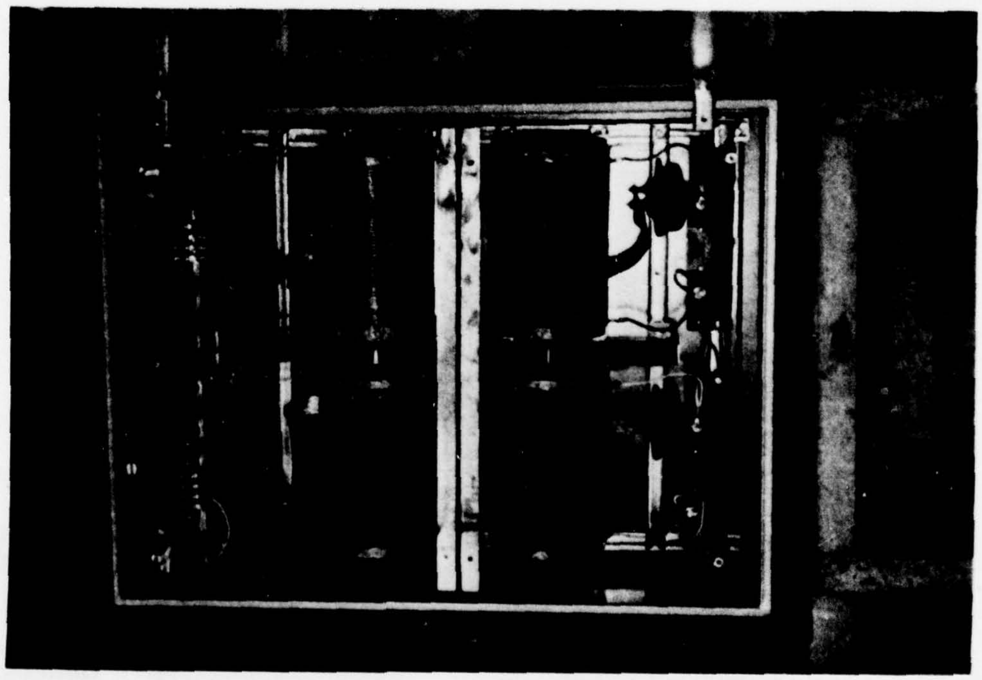


Figure 5 SURGE EFFICIENCY OF A LV 3 KVA 1 WIRE PROTECTION DEVICE



1 WIRE - 3 KVA - IMPEDANT NEUTRAL



LV 3 WIRES - 9 KVA - IMPEDANT NEUTRAL

Figure 6 LOW VOLTAGE PROTECTION DEVICES

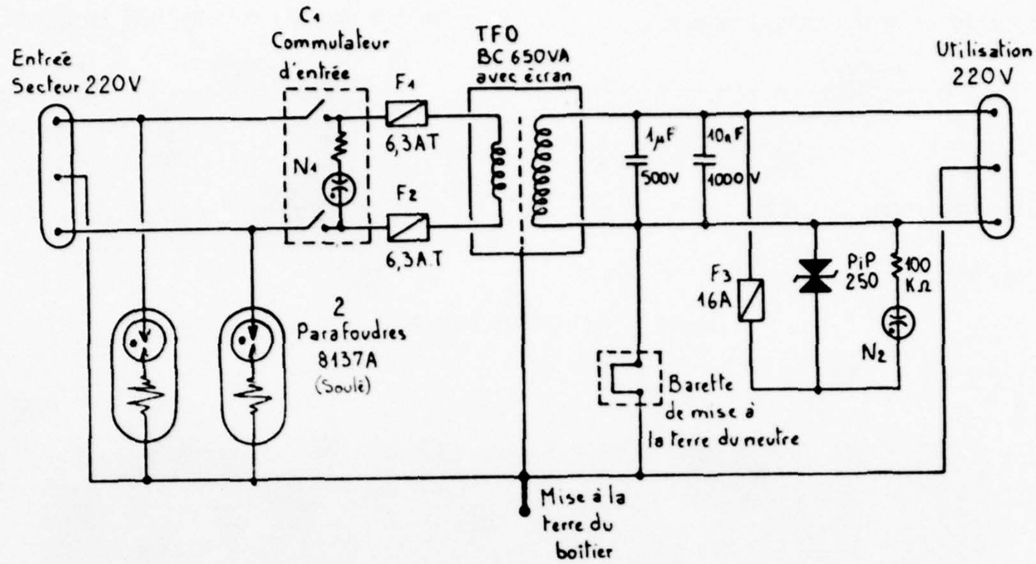
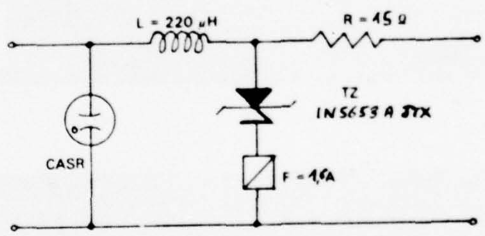
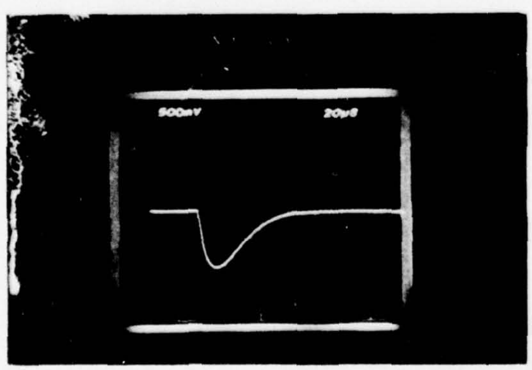
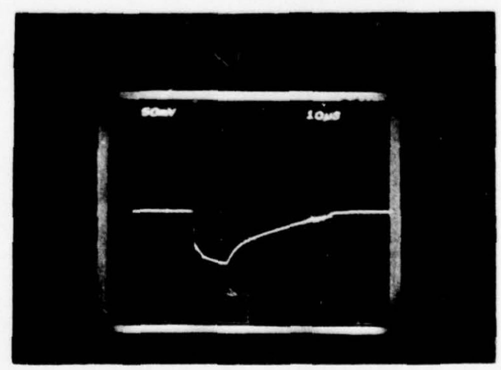


Figure 7 LV DECOUPLING PROTECTION DEVICE



RED 04





IMPULSE

OUTPUT

Figure 8 TEST RESULTS ON A RED 04 DEVICE

DEVICE YELLOW 02 (FOR POSITIVE SIGNALS)

DEVICE BLUE 09 (FOR BIPOLAR SIGNALS)

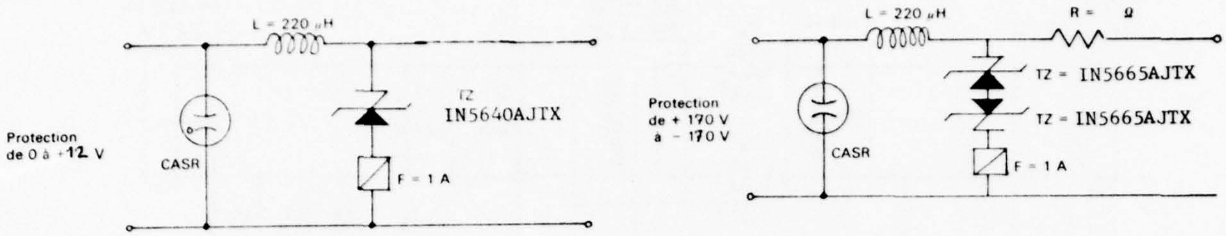


Figure 9 PROTECTION DEVICES

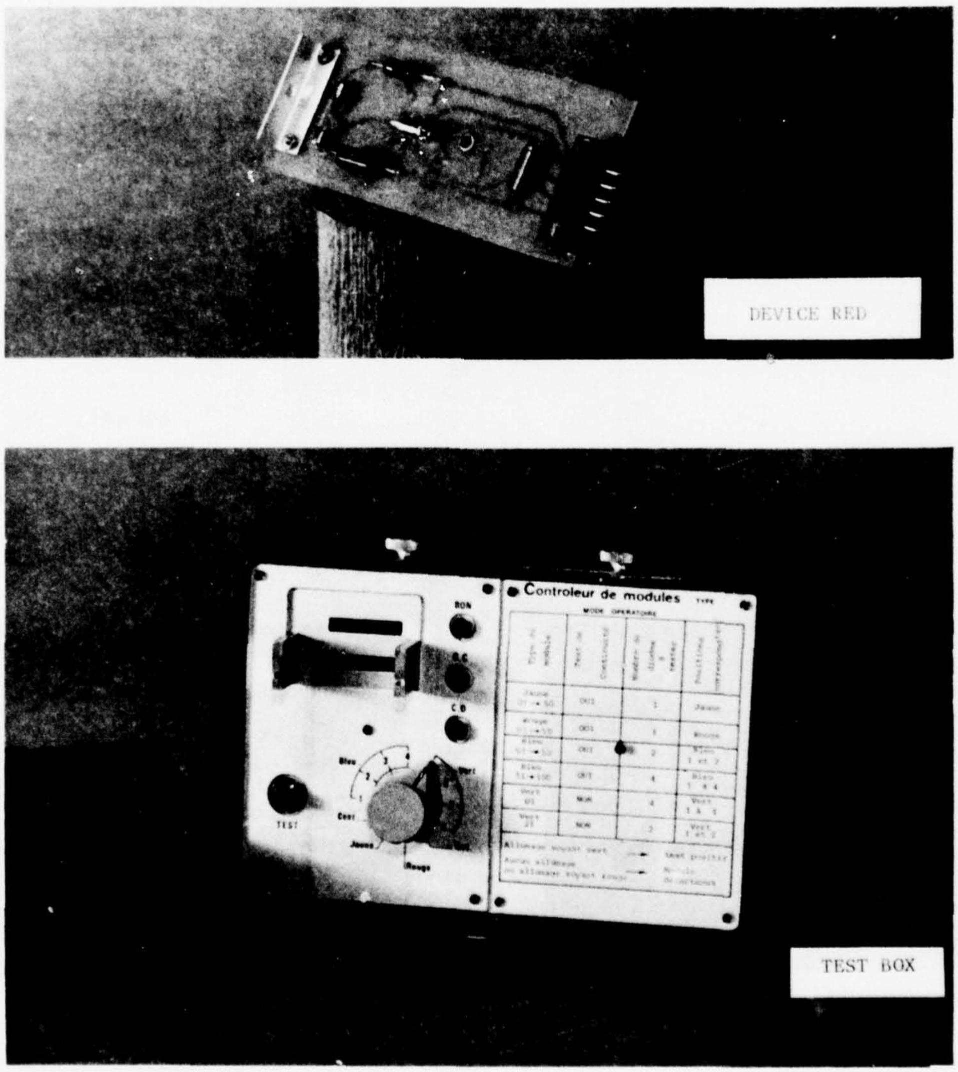


Figure 10 SIGNAL PROTECTION DEVICES

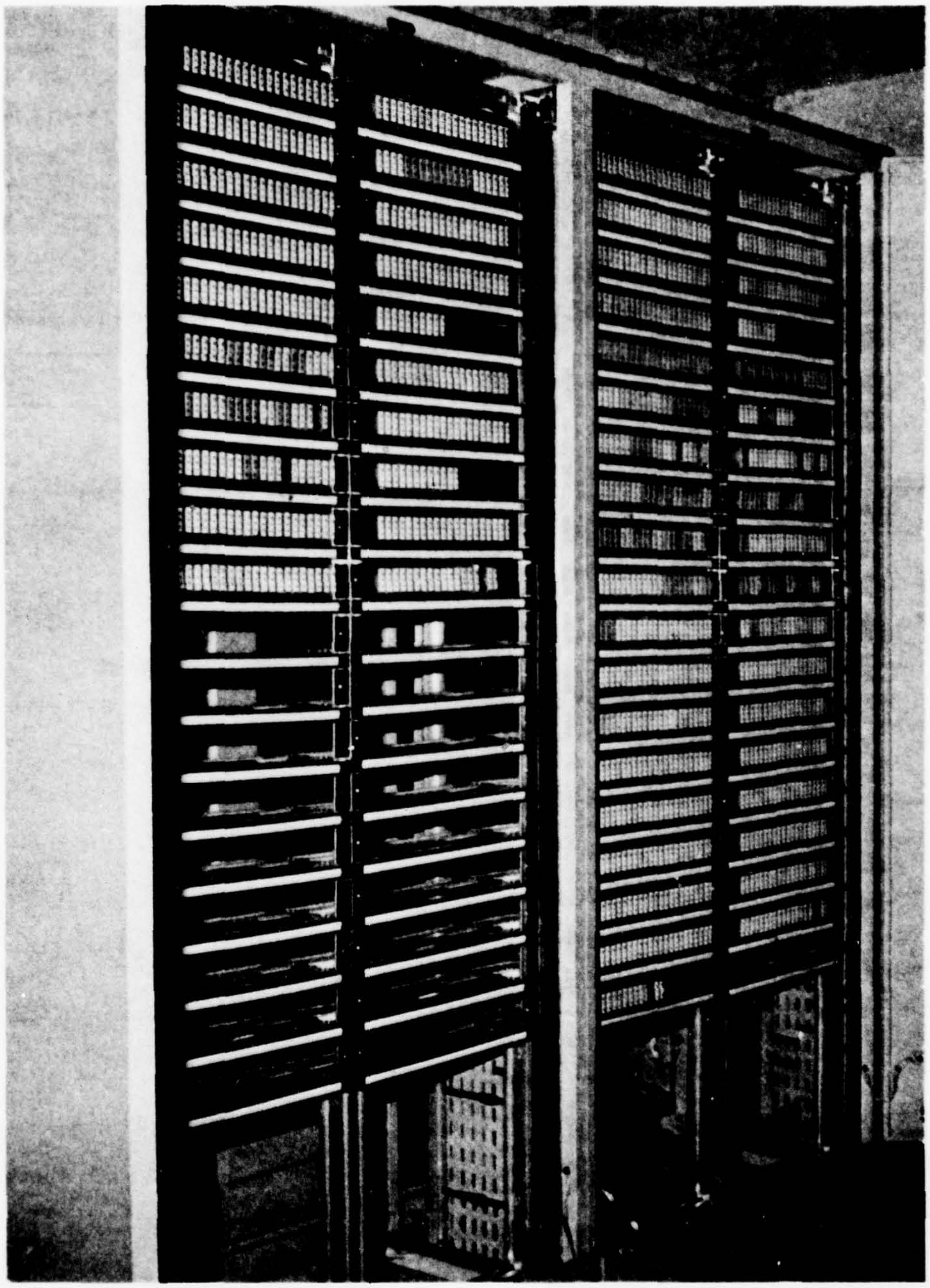


Figure 11   MODULES EN PLACE DANS LES ARMOIRES (TOUR SUD)

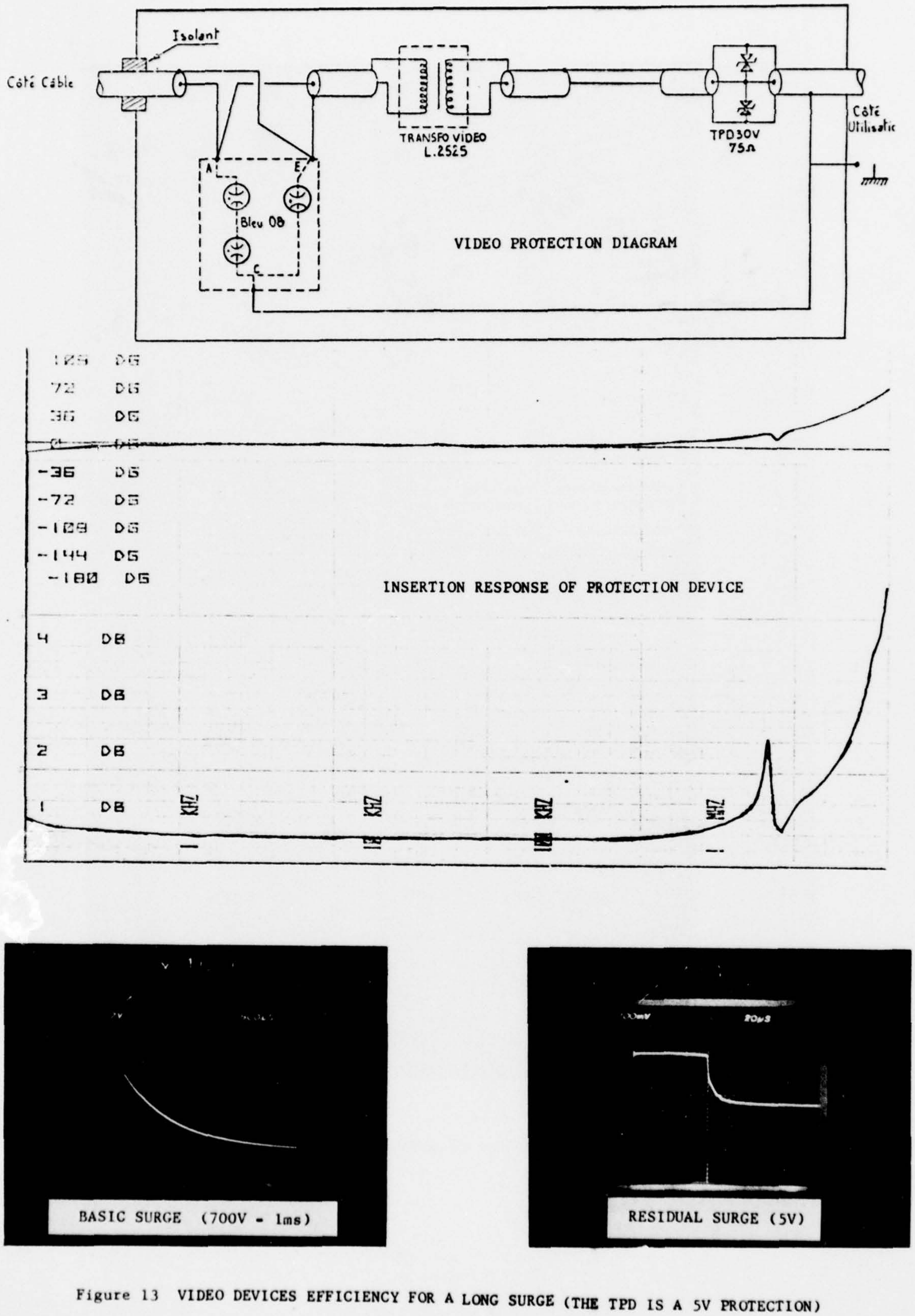
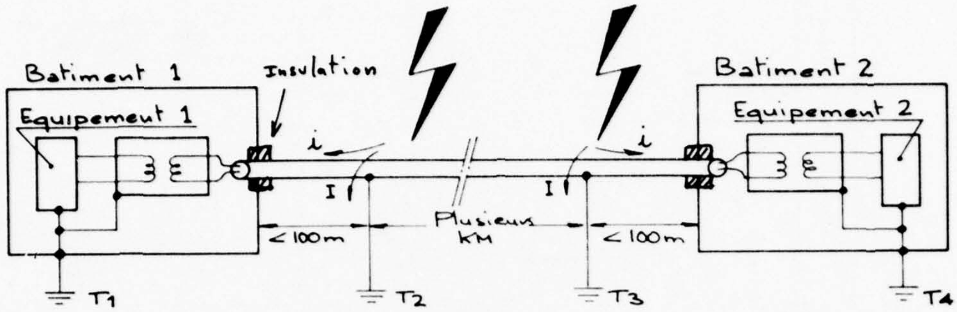
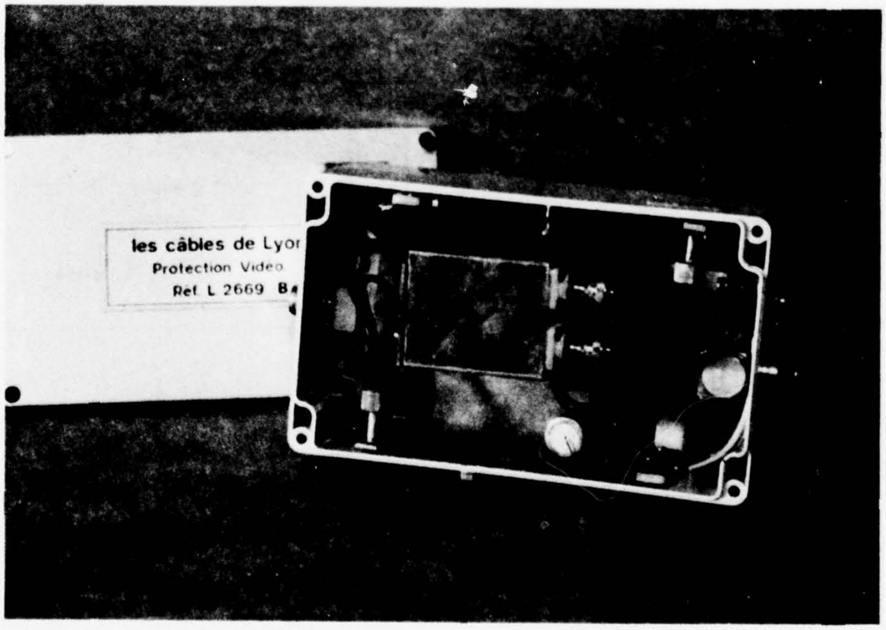


Figure 13 VIDEO DEVICES EFFICIENCY FOR A LONG SURGE (THE TPD IS A 5V PROTECTION)



GROUND ARRANGEMENT OF A BI-COUPLED LINE



VIDEO PROTECTION DEVICE

Figure 14

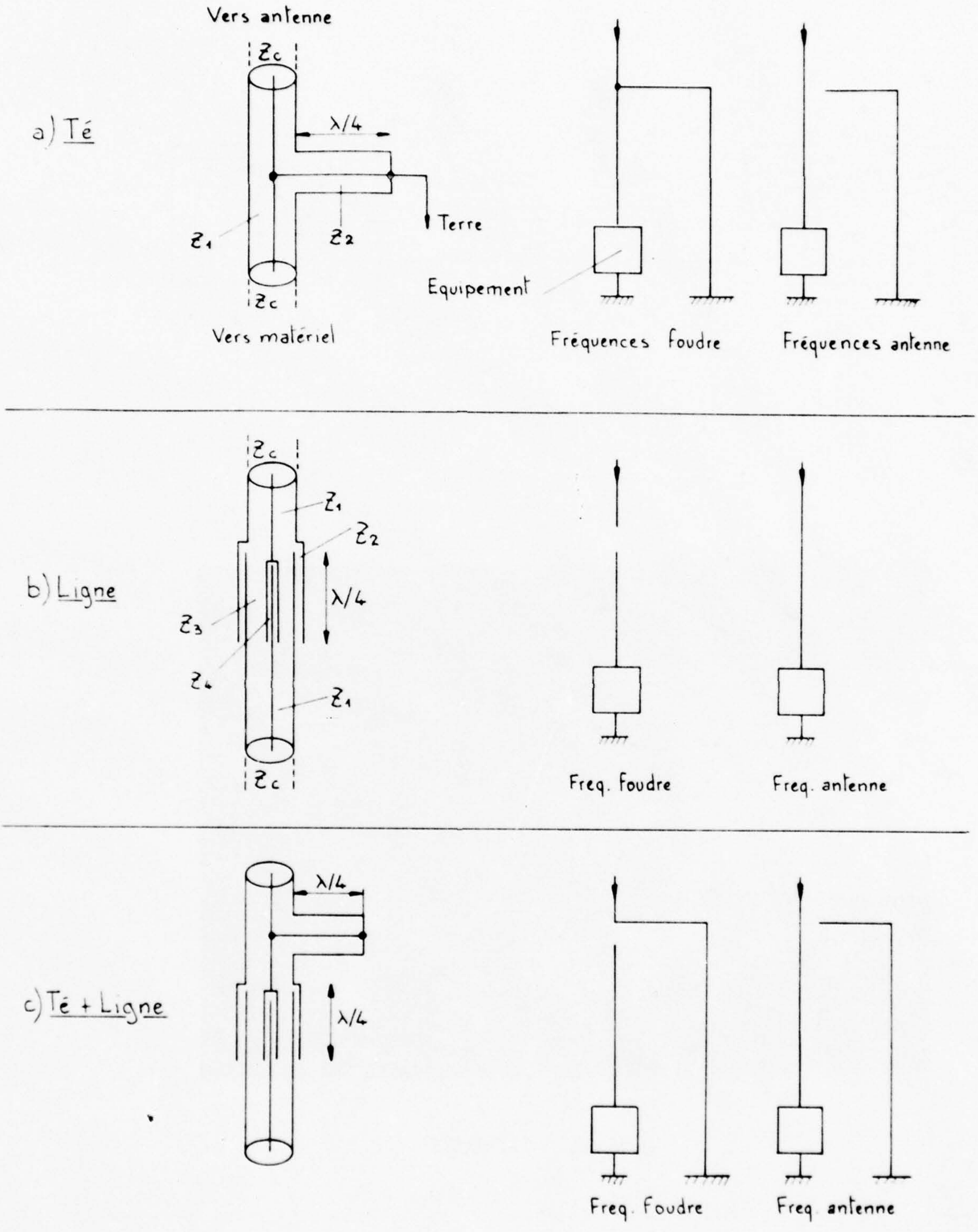


Figure 15 COAXIAL PROTECTION DEVICE

1 TYPE REFERENCE	2 NAME	3 PASS BAND IN MHz FOR VSWR GIVEN IN 8	4 CENTRAL FREQUENCY (MH3)	5 IMPEDANCE	6 INSERTION LOSS (F1 to F2) in db	7 INSERTION LOSS (db) at 100 KHz	8 VSWR MAXI (F1 to F2)
L 2488	VHF TEE	70 - 80	75	60 Ω	< 0.2	40	1.08
L 2428	VHF TEE	70 - 80	75	50 Ω	"	40	1.08
L 2427 B	VHF TEE	118 - 136	127	60 Ω	"	35	1.10
L 2427	VHF TEE	118 - 136	127	50 Ω	"	35	1.10
L 2426 B	UHF TEE	220 - 400	310	60 Ω	"	52	1.15
L 2426 A	UHF TEE	220 - 400	310	50 Ω	"	52	1.12
L 2481	TV TEE	466 - 622	546	60 Ω	"	55	1.15
L 2425	TV TEE	174 - 195	185	60 Ω	"	48	1.06
L 2716	VHF TEE	100 - 200	150	50 Ω	0.5	> 80	1.15
L 2402	L BAND TEE	1.5 - 2.3 GHz	1,9 GHz	50 Ω	0.5	60	1.25
L 2482	VHF DECOUPLING LINE	118 - 136	127	50 Ω	0.2	46	1.12
L 2483	UHF DECOUPLING LINE	220 - 400	310	50 Ω		50	1.15

Figure 16 TECHNICAL CHARACTERISTICS OF SOME COAXIAL PROTECTION DEVICES

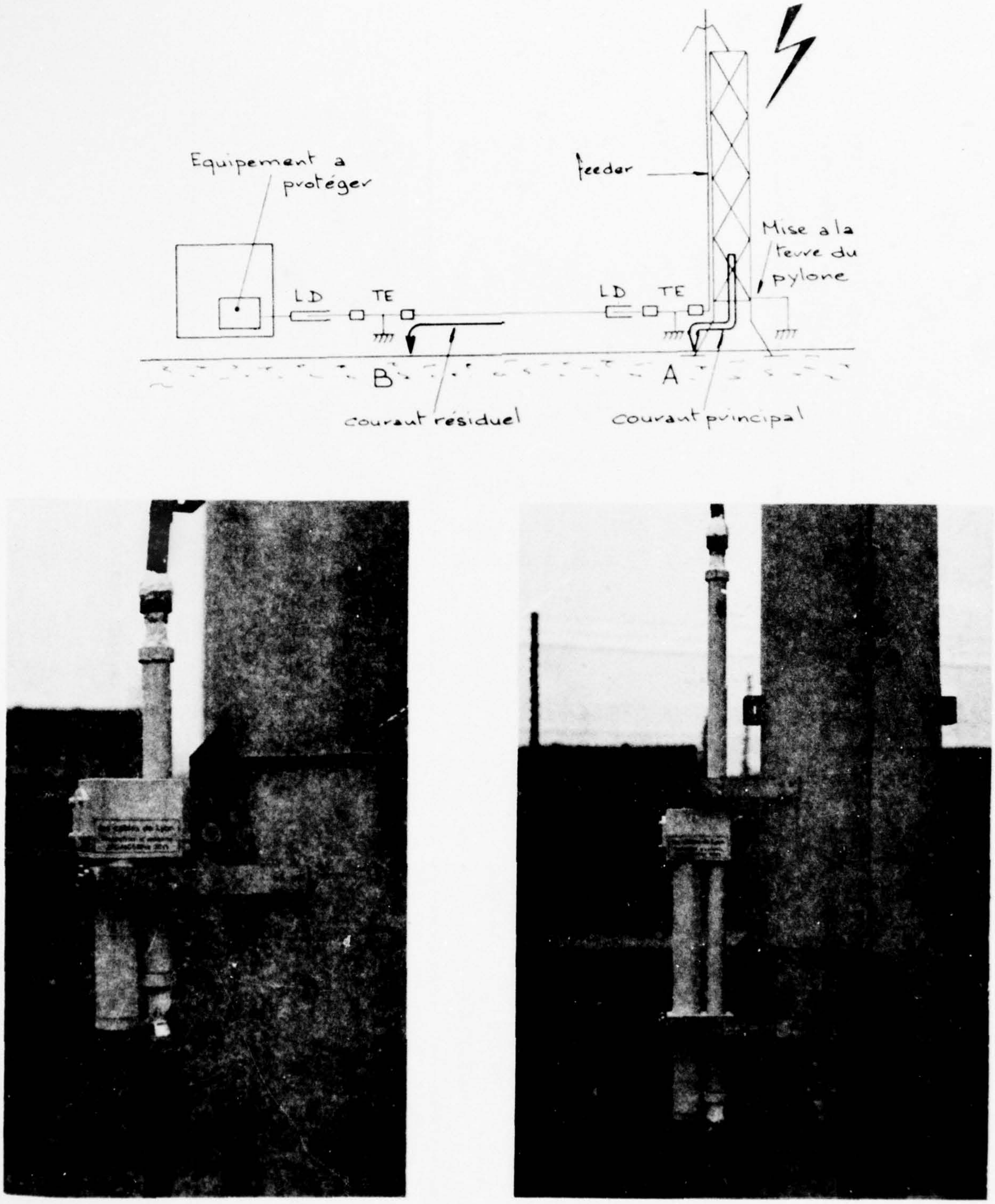


Figure 17 HF COAXIAL DEVICES - INSTALLATION EXAMPLE

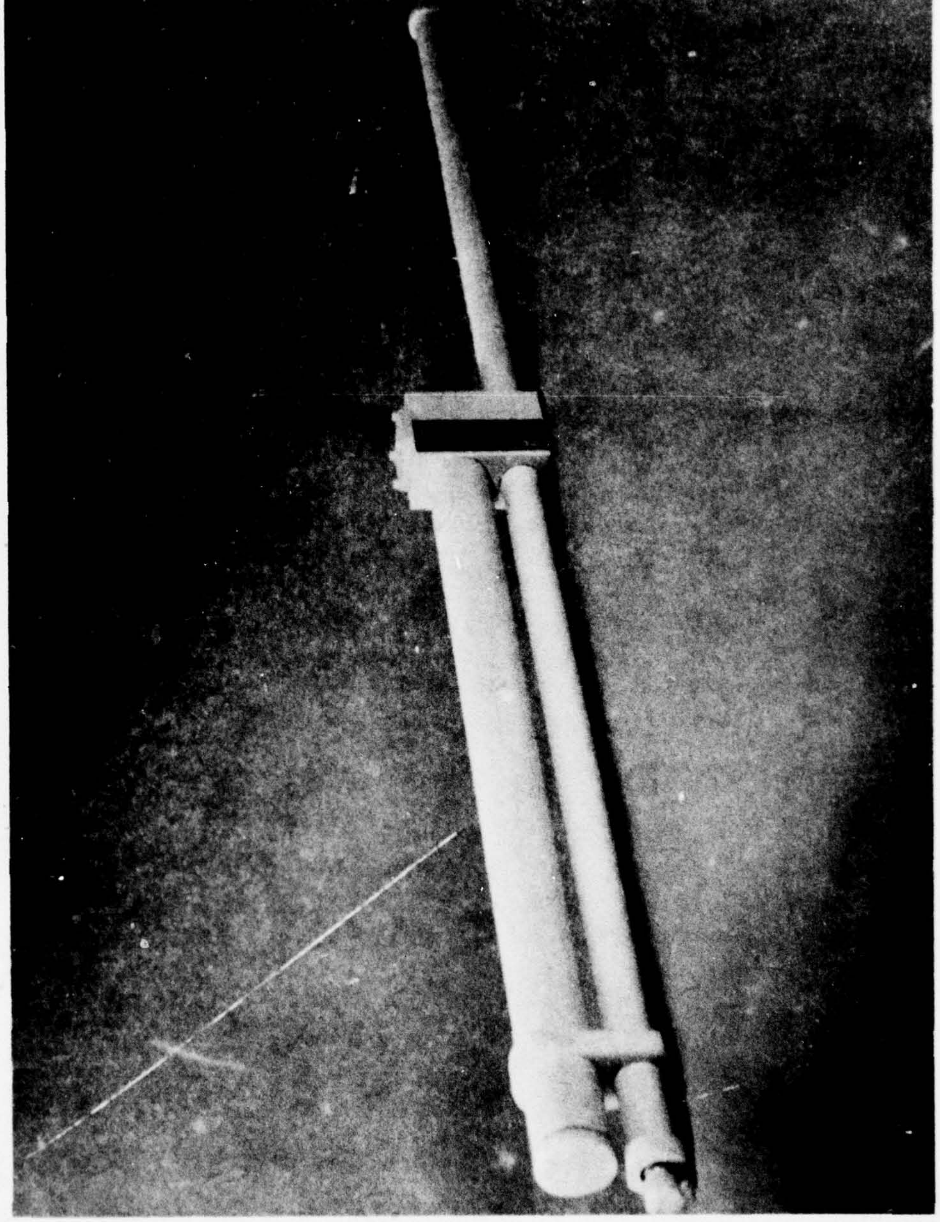


Figure 18A TEE FOR 70 - 80 MHz BAND

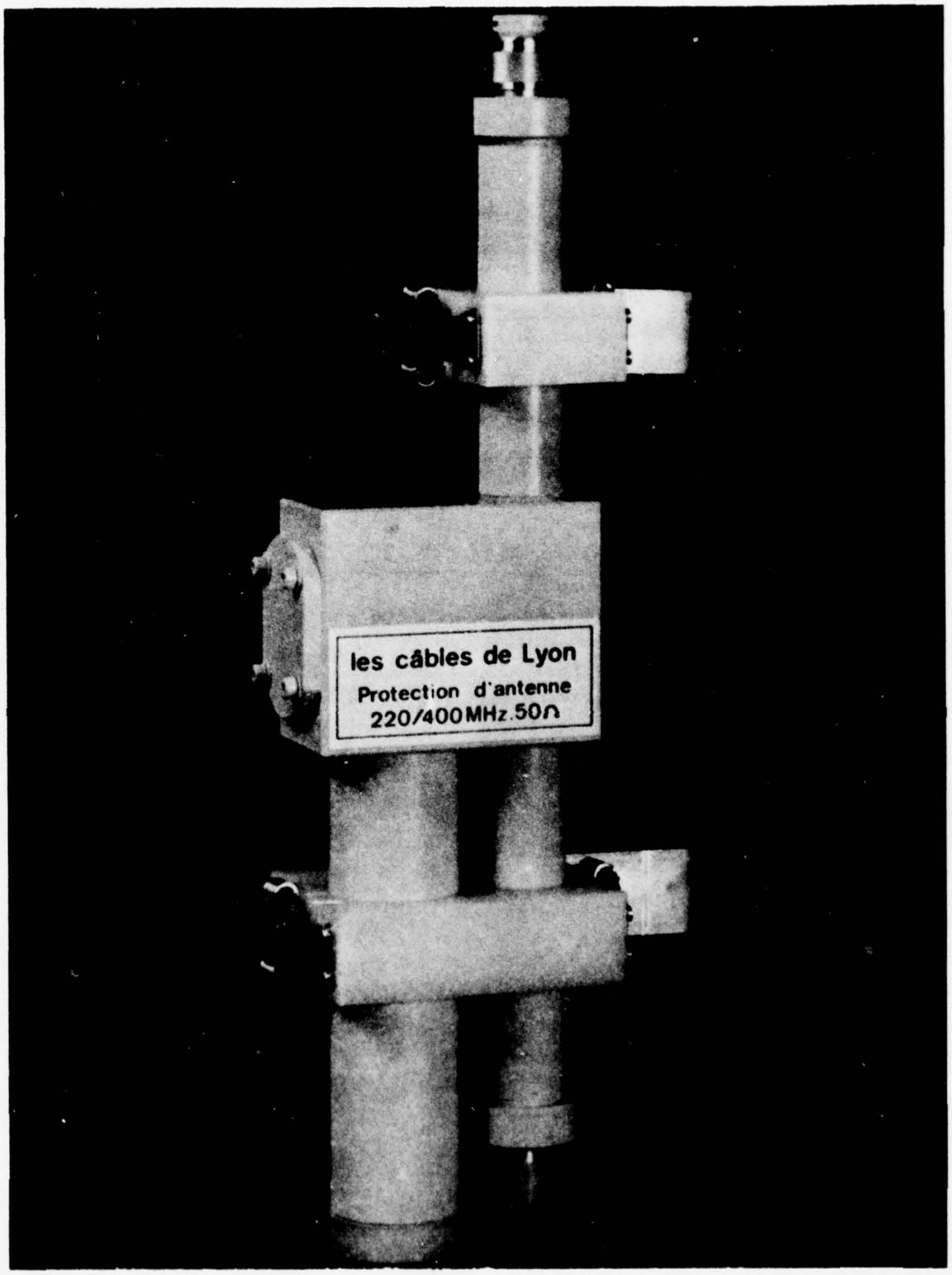


Figure 18B TEE FOR UHF BAND

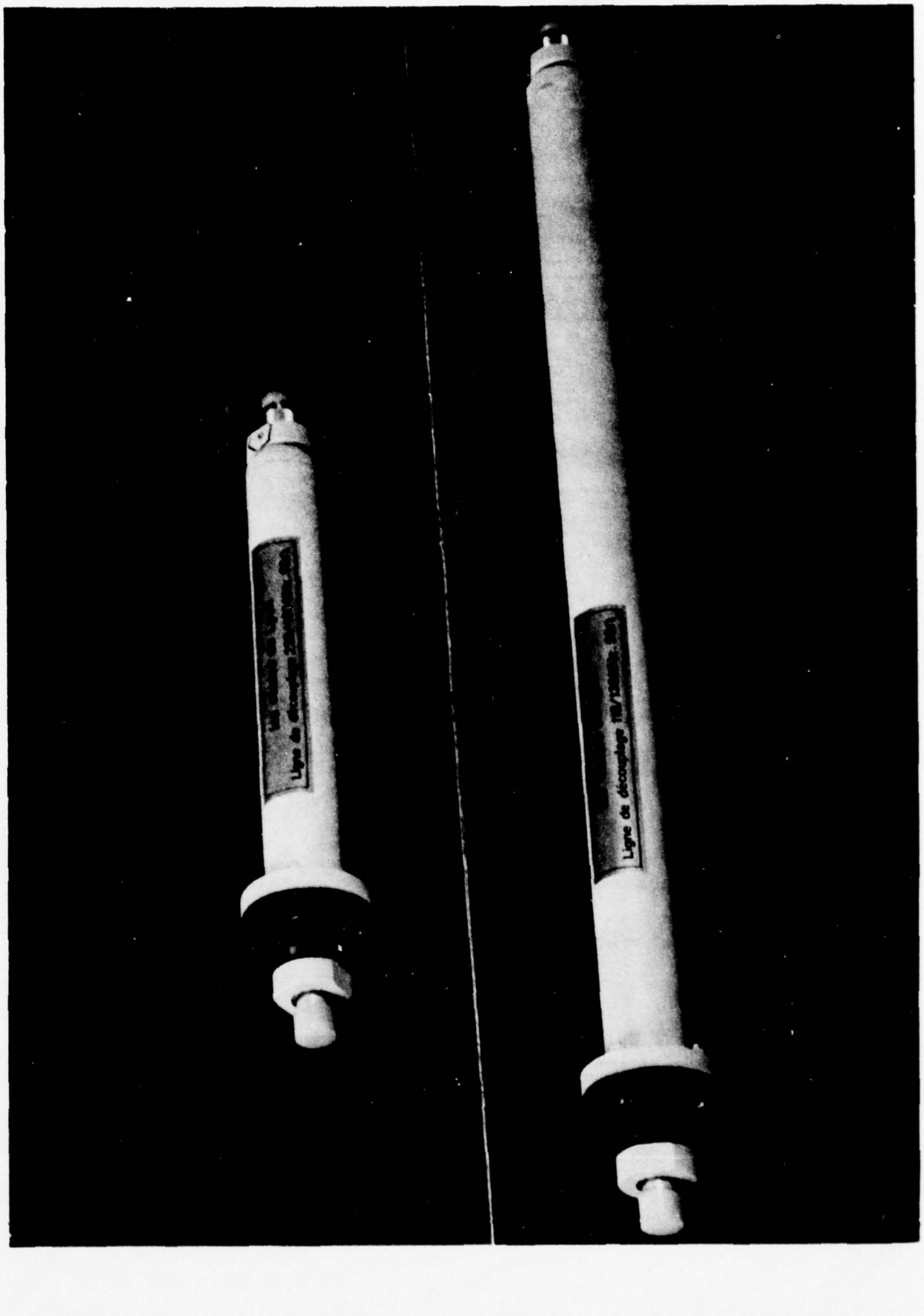


Figure 18C DECOUPLING COAXIAL DEVICE (VHF AND UHF)

Lightning Fatalities: Can they be prevented?

William E. Cobb

Atmospheric Physics and Chemistry Laboratory
National Oceanic and Atmospheric Administration
Boulder, Colorado 80303

Submitted to the

Workshop on Grounding and Lightning Technology

March 6-8, 1979 Melbourne, Florida

PRECEDING PAGE BLANK-NOT FILMED

A few months ago I was asked to supply some lightning information to the U.S. Attorney's Office in San Francisco for their use in defending the United States and the National Park Service in the upcoming court case, Brady v. U. S. Some aspects of the case are quite interesting.

Mr. Brady was killed by lightning in August 1975 while ascending a stairway up the side of Moro Rock, a popular tourist attraction in Sequoia National Park. As you can see in this slide the rock formation does look rather attractive for lightning. THe Brady heirs allege that as guests of the Park they were not properly warned of the lightning danger on Moro Rock.

At the time of the lightning stroke there were 25 people at various places along the walkway from the parking lot to the top of Moro Rock. Brady was about half way to the top under a slight rock overhang when he was killed. The coroner's report indicated only small burn marks on the forehead and left foot but massive internal heart damage. One man at the summit suffered a scull fracture and is permanently disabled--his clothing was entirely blown off. Six others suffered minor injuries. Let me show you a picture taken at the summit of Moro Rock just before the fatal lightning stroke. Ignorance is bliss, as these smiling faces indicate. I once measured an electric field of 80,000 V m^{-1} atop a mountain peak in Yellowstone Park and I can assure you that the electric field at the time these pictures were taken was at least that high. Of course, these kids were very foolish to stand there like lightning rods, waiting for disaster. You can see how the lines of force are concentrated around their heads from the way their hair

stands up. And yet, the man who was killed was halfway down the side under a rock ledge.

The U.S. Attorney's Office asked me if the probability of lightning striking a certain location could be determined, in this case, Moro Rock. Thunderstorms are uncommon in California with an average of 4 to 6 storms per year over most of the state and increasing to three times that number in the High Sierras. Moro Rock at 6725 ft. can expect about 12 storms annually. Using a formula derived by Pierce (EOS, 1968 Vol. 49) I calculated that a 100 meter square area on top of Moro Rock could expect to be hit by lightning once in five years. There are many higher ridges and peaks in the park which have a higher probability of being hit by lightning, however, they do not have the concentration of tourists that Moro Rock can expect on a summer afternoon. I made fair-weather electric field measurements on top of Moro Rock and at the parking area at the base of the rock in order to determine the field enhancement at the summit and found a 7 percent higher field on top of the rock formation. The difference is not as large as one might expect and indicates that lightning is only slightly more likely to hit the top of the rock than in the forested terrain around the base.

It is doubtful that any reasonable measures, other than staying in his car, could have prevented Mr. Brady's death. My concern, however, is for the many lightning-caused deaths and injuries that occur annually in the U.S., rather than the outcome of these particular court preceedings. As you probably know, lightning is the leading cause of weather-related fatalities in the U.S.A., exceeding flash floods, tornadoes and hurricanes. Why? I think part of the reason lies in the general attitude that lightning fatalities are "an

act of God" and that 150 to 300 people will be killed each year regardless of any action taken.

In an attempt to reduce lightning fatalities we need to recognize the fact that the electric field is a physical quantity for which we have no sense organ and thus people who seek shelter from the rain will stand on top of a rock in extremely high fields and not realize the danger they are exposed to. I have often thought that if it always rained where lightning was striking the ground, not many people would be killed.

For the most part, lightning protection for individuals in this country consists of a set of safety rules published in National Weather Service brochures and occasionally in the newspapers following a fatal accident. While this workshop is more concerned with lightning technology and the protection of instruments and vehicles, I can't think of a better place than before this group to empahsize the need for a reliable, relatively low cost, lightning warning device which might save the lives of people such as the tourists on Moro Rock, the two little leagers killed last summer near my home in Colorado, or the young lady killed on Cocoa Beach a few years ago during the International Thunderstorm Research Project.

Certainly there are research institutions and scientific companies represented here that are capable of designing and marketing successful lightning warning devices that could be used at beaches, golf courses, national parks, etc. across the country.

This report was referenced in J. Anderson Plumer's paper "A New Standard For Lightning Qualification Testing of Aircraft", page 155 of FAA-RD-79-6 and is included in the supplement because of the interest shown in the document.

LIGHTNING TEST WAVEFORMS AND TECHNIQUES FOR AEROSPACE VEHICLES AND HARDWARE

Report of

SAE Committee AE4L

June 20, 1978

Users of this document should ascertain that they are in possesion of the latest version.

This version supersedes SAE Special Task F Report "Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware" dated May 5, 1976.

Information concerning the status of this document, and additional copies of it, may be obtained from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pa. 15096.

1.0 INTRODUCTION

This document presents test waveforms and techniques for simulated lightning testing of aerospace vehicles and hardware. The waveforms presented are based on the best available knowledge of the natural lightning environment coupled with a practical consideration of state-of-the-art laboratory techniques. This document does not include design criteria nor does it specify which items should or should not be tested.

Tests and associated procedures described herein are divided into two general categories:

- o Qualification tests
- o Engineering tests

Acceptable levels of damage and/or pass-fail criteria for the qualification tests must be provided by the cognizant regulatory authority for each particular case.

The engineering tests provide important data that may be necessary to achieve a qualifiable design.

The term Aerospace Vehicle covers a wide variety of systems, including fixed wing aircraft, helicopters, missiles, and spacecraft. In addition, natural lightning is a complex and variable phenomenon and its interaction with different types of vehicles may be manifested in many different ways. It is therefore difficult to address every possible situation in detail. However, the test waveforms described herein represent the significant aspects of the natural environment and are therefore independent of vehicle type or configuration. The recommended test techniques have also been kept general to cover as many test situations as possible. Some unique situations may not fit into the general guidelines; in such instances, application of the waveform components must be tailored to the specific situation.

The test waveforms and techniques described herein for qualification tests simulate the effects of a severe lightning strike to an aerospace vehicle. Where it has been shown that test conditions can affect results of the test, a specific approach is recommended as a guideline to new laboratories and for consistency of results between laboratories.

It is not intended that every waveform and test described herein be applied to every system requiring lightning verification tests. The document is written so that specific aspects of the environment can be called out for each specific program as dictated by the vehicle design, performance, and mission constraints.

2.0 LIGHTNING STRIKE PHENOMENA

2.1 Natural Lightning Strike Electrical Characteristics

Lightning flashes are of two fundamentally different forms, cloud-to-ground flashes and inter/intracloud flashes. Because of the difficulty of intercepting and measuring inter/intracloud flashes the great bulk of the statistical data on the characteristics of lightning refer to cloud-to-ground flashes. Aerospace vehicles intercept both inter/intracloud and cloud-to-ground lightning flashes as shown in Figure 2-1. There is evidence that the inter/intracloud flashes lack the high peak currents of cloud-to-ground flashes. Therefore, the use of cloud-to-ground lightning strike characteristics as design criteria for lightning protection seems conservative.

There can be discharges from either a positive or a negative charge center in the cloud. A negative discharge is characterized by several intermittent strokes and continuing currents as shown in Figure 2-2(A). A positive discharge, which occurs only a small but significant percentage of the time, is shown in Figure 2-2(B). It is characterized by both higher average current and longer duration in a single stroke and must be recognized because of its greater energy content. The following discussion describes the more common negative flashes.

2.1.1 Prestrike Phase

The lightning flash is typically originated by a step leader which develops from the cloud toward the ground or towards another charge center. As a lightning step leader approaches an extremity of the vehicle, high electrical fields are produced at the surface of the vehicle. These electric fields give rise to other electrical streamers which propagate away from the vehicle until one of them contacts the approaching lightning step leader as shown on Figure 2-1. Propagation of the step leader will continue from other vehicle extremities until one of the branches of the step leader reaches the ground or another charge center. The average velocity of propagation of the step leader is about one meter per microsecond and the average charge in the whole step leader channel is about 5 coulombs.

2.1.2 High Peak Current Phase

The high peak current associated with lightning occurs after the step leader reaches the ground and forms what is called the return stroke of the lightning flash. This return stroke occurs when the charge in the leader channel is suddenly able to flow into the low impedance ground and neutralize the charge attracted into the region prior to the step leader's contact with the ground. Typically, the high peak current phase is called the return stroke and is in the range of 10 to 30 kA (amperes x 10^3). Higher currents are possible though less probable. A peak current of 200 kA represents a very severe stroke, one that is exceeded only about 0.5 percent of the time. While 200 kA may be considered a practical maximum value of lightning current, it should be emphasized that in rare cases a larger current can occur. Reliable measurements are few, but there is circumstantial evidence that peak currents can exceed 400 kA. The current in the return stroke has a fast rate of change, typically about 10 to 20 kA per micro-

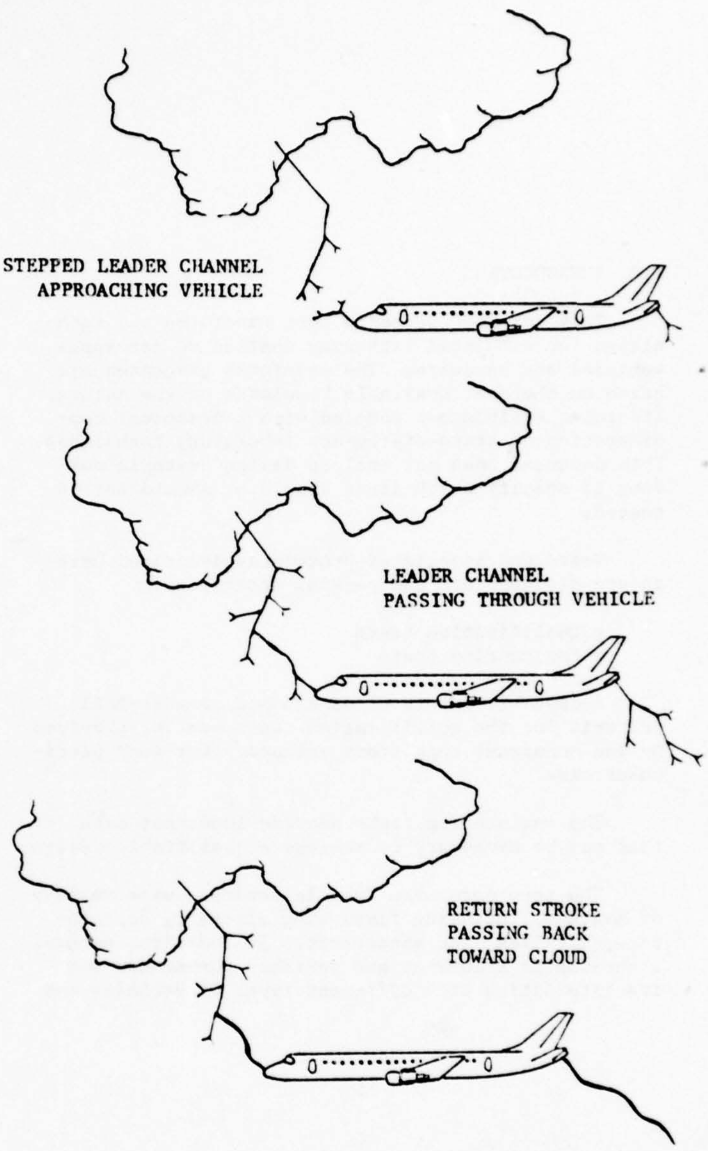


Fig. 2-1 Lightning flash striking an aircraft.

second and exceeding, in rare cases, 100 kA per microsecond. Typically the current decays to half its peak amplitude in 20 to 40 µsec. No correlation has been shown to exist between peak current and rate of rise.

2.1.3 Continuing Current

The total charge transported by the lightning return stroke is relatively small, a few coulombs. Most of the charge is transported in two phases of the lightning flash following the first return stroke. These are an intermediate phase in which currents of a few thousand amperes flow for times of a few milliseconds and a continuing current phase in which currents of the order of 200-400 amperes flow for times varying from about a tenth of a second to one second. The maximum charge transferred in the intermediate phase is about 10 coulombs and the maximum charge transported during the total continuing current phase is about 200 coulombs.

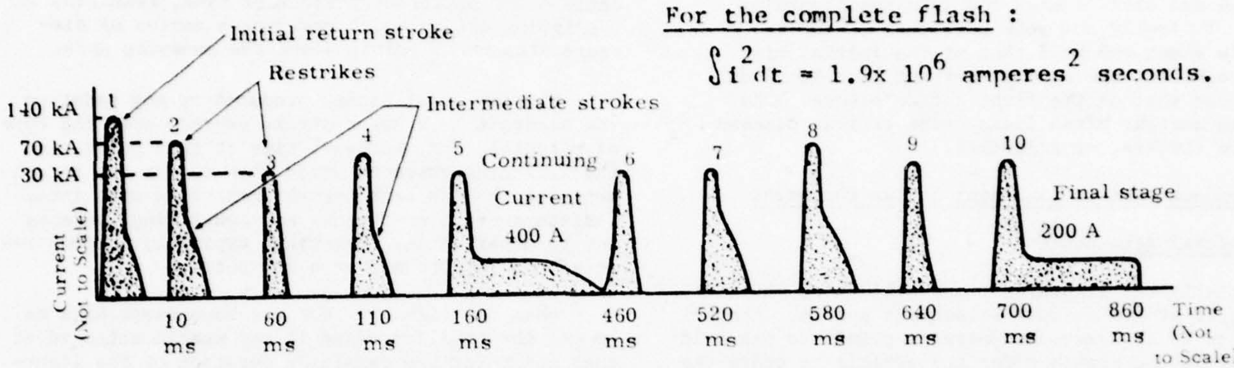
For each stroke:

Time to peak current = 1.5 μs

Time to Half Value = 40 μs

For the complete flash :

$\int i^2 dt = 1.9 \times 10^6$ amperes^2 seconds.

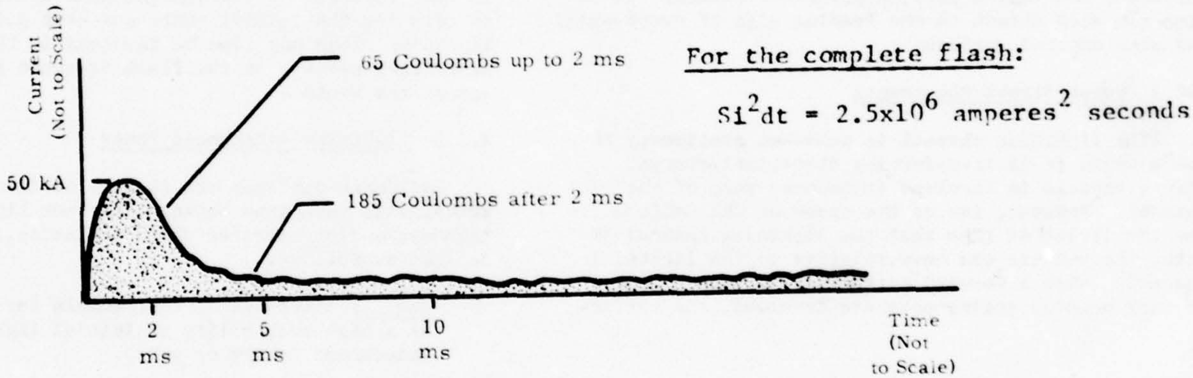


(A) Severe negative lightning flash current waveform.

(Courtesy of Cianos/Pierce)

For the complete flash:

$\int i^2 dt = 2.5 \times 10^6$ amperes^2 seconds



(B) Moderate positive lightning flash current waveform.

Figure 2-2 Lightning flash current waveforms.

2.1.4 Restrike Phase

In a typical lightning flash there will be several high current strokes following the first return stroke. These occur at intervals of several tens of milliseconds as different charge pockets in the cloud are tapped and their charge fed into the lightning channel. Typically the peak amplitude of the restrikes is about one half that of the initial high current peak, but the rate of current rise is often greater than that of the first return stroke. The continuing current often links these various successive return strokes, or restrikes.

2.2 Aerospace Vehicle Lightning Strike Phenomena

2.2.1 Initial Attachment

Initially the lightning flash will enter and exit the aircraft at two or more attachment points. There will always be at least one entrance point and one exit point. It is not possible for the vehicle to store the electrical energy of the lightning flash in the capacitive field of the vehicle and so avoid an exit point. Typically these initial attachment points are at the extremities of the vehicle. These include the nose, wing tips, elevator and stabilizer tips, protruding antennas, and engine pods or propeller blades. Lightning can also attach to the leading edge of swept wings and some control surfaces.

2.2.2 Swept Stroke Phenomenon

The lightning channel is somewhat stationary in space while it is transferring electrical charge. When a vehicle is involved it becomes part of the channel. However, due to the speed of the vehicle and the length of time that the lightning channel exists, the vehicle can move relative to the lightning channel. When a forward extremity, such as a nose or wing mounted engine pods are involved, the surface moves through the lightning channel. Thus the lightning channel appears to sweep back over the surface as illustrated in Figure 2-3. This is known as the swept stroke phenomenon. As the sweeping action occurs, the type of surface can cause the lightning channel attach point to dwell at various surface locations for different periods of time, resulting in a skipping action which produces a series of discrete attachment points along the sweeping path.

The amount of damage produced at any point on the aircraft by a swept-stroke depends upon the type of material, the arc dwell time at that point, and the lightning currents which flow during the attachment. Both high peak current restrikes with intermediate current components and continuing currents may be experienced. Restrikes typically produce reattachment of the arc at a new point.

When the lightning arc has been swept back to one of the trailing edges it may remain attached at that point for the remaining duration of the lightning flash. An initial exit point, if it occurs at a trailing edge, of course, would not be subjected to any swept stroke action.

The significance of the swept stroke phenomenon is that portions of the vehicle that would not be targets for the initial entry and exit point of a lightning flash may also be involved in the lightning flash process as the flash is swept backwards across the vehicle.

2.2.3 Lightning Attachment Zones

Aircraft surfaces can then be divided into three zones, with each zone having different lightning attachment and/or transfer characteristics. These are defined as follows:

Zone 1: Surfaces of the vehicle for which there is a high probability of initial lightning flash attachment (entry or exit).

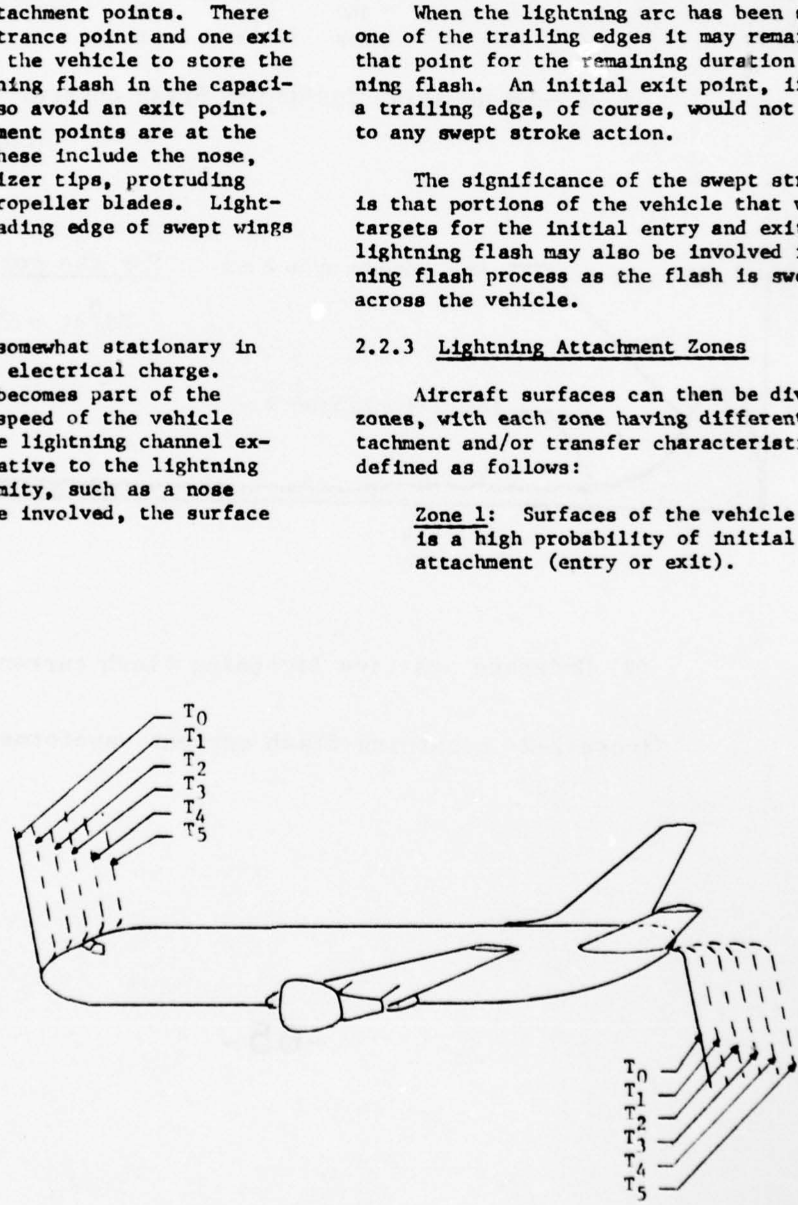


Figure 2-3 Swept stroke phenomenon.

Zone 2: Surfaces of the vehicle across which there is a high probability of a lightning flash being swept by the airflow from a Zone 1 point of initial flash attachment.

Zone 3: Zone 3 includes all of the vehicle areas other than those covered by Zone 1 and Zone 2 regions. In Zone 3 there is a low probability of any attachment of the direct lightning flash arc. Zone 3 areas may carry substantial amounts of electrical current but only by direct conduction between some pair of direct or swept stroke attachment points.

Zones 1 and 2 may be further divided into A and B regions depending on the probability that the flash will hang on for any protracted period of time. An A type region is one in which there is low probability that the arc will remain attached and a B type region is one in which there is a high probability that the arc will remain attached. Some examples of zones are as follows:

Zone 1A: Initial attachment point with low probability of flash hang-on, such as a leading edge.

Zone 1B: Initial attachment point with high probability of flash hang-on, such as a trailing edge.

Zone 2A: A swept stroke zone with low probability of flash hang-on, such as a wing mid-span.

Zone 2B: A swept stroke zone with high probability of flash hang-on, such as a wing inboard trailing edge.

2.3 Aerospace Vehicle Lightning Effects Phenomena

The lightning effects to which aerospace vehicles are exposed and the effects which should be reproduced through laboratory testing with simulated lightning waveforms can be divided into DIRECT EFFECTS and INDIRECT EFFECTS. The direct effects of lightning are the burning, eroding, blasting, and structural deformation caused by lightning arc attachment, as well as the high-pressure shock waves and magnetic forces produced by the associated high currents. The indirect effects are predominatly those resulting from the interaction of the electromagnetic fields accompanying lightning with electical apparatus in the aircraft. Hazardous indirect effects could in principle be produced by a lightning flash that did not directly contact the aircraft and hence was not capable of producing the direct effects of burning and blasting. However, it is currently believed that most indirect effects of importance will be associated with a direct lightning flash. In some cases both direct and indirect effects may occur to the same component of the aircraft. An example would be a lightning flash to an antenna which physically damages the antenna and also sends damaging voltages into the transmitter or receiver connected to that antenna. In this document the physical damage to the antenna will be discussed as a direct effect and the voltages or currents coupled from the antenna into the communications equipment will be treated as an indirect effect.

2.3.1 Direct Effects

The nature of the particular direct effects associated with any lightning flash depends upon the structural component involved and the particular phase of the lightning current transfer discussed earlier.

2.3.1.1 Burning and Eroding

The continuing current phase of a lightning stroke can cause severe burning and eroding damage to vehicle structures. The most severe damage occurs when the lightning channel dwells or hangs on at one point on the vehicle for the entire period of the lightning flash, such as in Zone 1B. This can result in holes of up to a few centimeters in diameter on the aircraft skin.

2.3.1.2 Vaporization Pressure

The high peak current phase of the lightning flash transfers a large amount of energy in a short period of time, a few tens of microseconds. This energy transfer can result in a fast thermal vaporization of material. If this occurs in a confined area such as a radome, a high pressure may be created which may be of sufficient magnitude to cause structural damage. The vaporization of metal and other materials and the heating of the air inside the radome, create the high internal pressure that leads to structural failure. In some instantces intire radomes have been blown from the aircraft.

2.3.1.3 Magnetic Force

During the high peak current phase of the lightning flash the flow of current through sharp bends or corners of the aircraft structure can cause extensive magnetic flux interaction. In certain cases, the resultant magnetic forces can twist, rip, distort, and tear structures away from rivets, screws, and other fasteners. These magnetic forces are proportional to the square of the magnetic field intensity and thus are proportional to the square of the lightning current. The damage produced is related both to the magnetic force and to the response time of the system.

2.3.1.4 Fire and Explosion

Fuel vapors and other combustibles may be ignited in several ways by a lightning flash. During the prestrike phase high electrical stresses around the vehicle produce streamers from the aircraft extremities. The design and location of fuel vents determine their susceptibility to streamer conditions. If streamers occur from a fuel vent in which flammable fuel-air mixtures are present, ignition may occur. If this ignition is not arrested, flames can propagate into the fuel tank area and cause a major fuel explosion.

The flow of lightning current through vehicle structures can cause sparking at poorly bonded structure interfaces or joints. If such sparking occurs where combustibles such as fuel vapors are located, ignition may occur.

Lightning attaching to an integral tank skin may puncture, burn holes in the tank, or heat the inside surface sufficiently to ignite any flammable vapors present.

2.3.1.5 Acoustic Shock

The air channel through which the lightning flash propagates is nearly instantaneously heated to a very high temperature. When the resulting shock wave impinges upon a surface it may produce a destructive overpressure and cause mechanical damage.

2.3.2 Indirect Effects

Damage or upset of electrical equipment by currents or voltages is defined as an indirect effect. In this document such damage or upset is defined as an indirect effect even though such currents or voltages may arise as a result of a direct lightning flash attachment to a piece of external electrical hardware. An example would be a wing-tip navigation light. If lightning shatters the protective glass covering or burns through the metallic housing and contacts the filament of the bulb, current can be injected into the electrical wires running from the bulb to the power supply bus. This current may burn or vaporize the wires. The associated voltage surge may cause breakdown of insulation or damage to other electrical equipment.

Even if the lightning flash does not contact wiring directly, it will set up changing electromagnetic fields around the vehicle. The metallic structure of the vehicle does not provide a perfect Faraday cage electromagnetic shield and therefore some electromagnetic fields can enter the vehicle, either by diffusion through metallic skins or direct penetration through apertures such as skin joints and windows or other nonmetallic sections. If the fields are changing with respect to time and link electrical circuits inside the vehicle, they will induce transient voltages and currents into these circuits. These voltages may be hazardous to avionic and electrical equipment, as well as a source of fuel ignition.

Voltages and currents may also be produced by the flow of lightning current through the resistance of the aircraft structure.

2.3.3 Effects on Personnel

One of the most troublesome effects on personnel is flash blindness. This often occurs to flight crew member(s) who may be looking out of the vehicle in the direction of the lightning flash. The resulting flash blindness may persist for periods of 30 seconds or more, rendering the crew member temporarily unable to use his eyes for flight or instrument-reading purposes.

Personnel inside vehicles may also be subjected to hazardous effects from lightning strikes. Serious electrical shock may be caused by currents and voltages, conducted via control cables or wiring leading to the cockpit from control surfaces or other hardware struck by lightning. Shock can also be induced by the intense thunderstorm electromagnetic fields.

The shock varies from mild to serious; sufficient to cause numbness of hands or feet and some disorientation or confusion. This can be quite hazardous in high-performance aircraft, particularly under the thunderstorm conditions during which lightning strikes generally occur.

Tests to evaluate these personnel effects are not included in this document.

3.0 STANDARD LIGHTNING PARAMETER SIMULATION

3.1 Purpose

Complete natural lightning flashes cannot be duplicated in the laboratory. Most of the voltage and current characteristics of lightning, however, can be duplicated separately by laboratory generators. These characteristics are of two broad categories: The VOLTAGES produced during the lightning flash and the CURRENTS that flow in the completed lightning channel. With a few exceptions, it is not necessary to simulate high-voltage and high-current characteristics together.

The high-voltage characteristics of lightning determine attachment points, breakdown paths, and streamer effects, whereas the current characteristics determine direct and indirect effects.

In most cases, lightning voltages are simulated by high-impedance voltage generators operating into high-impedance loads, while lightning currents are simulated by low-impedance current generators operating into low-impedance loads.

The waveforms described in this section are idealized. Definitions relating to actual waveshapes are covered in ANSI and IEEE Standard Techniques for Dielectric Tests. ANSI C68.1 (1968) and IEEE No. 4. These specifications are equivalent and are in turn equivalent to High Voltage Test Techniques, IEC 60-2 (1973). The definitions in these documents should be used to determine the front time, duration and rate of rise of actual waveforms.

Severe lightning flash voltage and current waveforms, as described in Paragraph 3.2 have been developed for purposes of qualification testing: waveforms in Paragraph 3.3 are for R&D or screening test purposes and are designated engineering tests.

3.2 Waveform Descriptions for Qualification Tests

3.2.1 Voltage Waveforms

The basic voltage waveform to which vehicles are subjected is one that rises until breakdown occurs either by puncture of solid insulation or flashover through the air or across an insulating surface. The path that the flashover takes, either puncture or surface flashover, depends on the rate of rise of the voltage as shown in Figure 3-1.

During some types of testing it is necessary to determine the critical voltage amplitude at which breakdown occurs. This critical voltage level depends upon both the rate of rise of voltage and the rate of voltage decay. Two examples are (1) determining the strength of the insulation used on electrical wiring and (2) determining the points from which electrical streamers occur on a vehicle as a lightning flash approaches.

Although the exact voltage waveform produced by natural lightning is not known, flight service data and conservative test philosophy justify the definition of fast rising voltage waveforms for the tests just described. Voltage testing for qualification purposes thus calls for two different standard voltage waveforms. These are shown in Figure 3-2 and are described in the following sections. The qualification tests in which these waveforms are applied are presented in the test matrix of Table 1. The objectives of each test, the test setup, measurement and data requirements are described in Section 4.0.

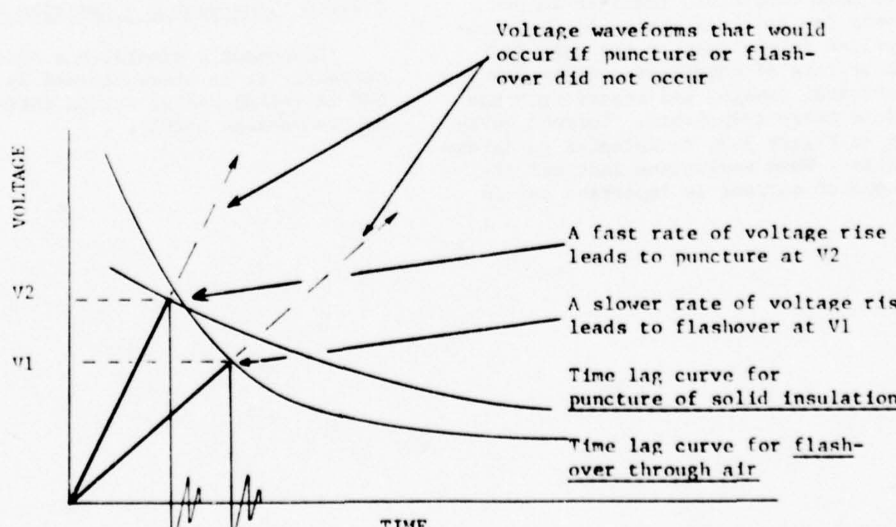


Figure 3-1 Influence of rate of rise on flashover path

3.2.1.1 Voltage Waveform A - Basic Lightning Waveform

This waveform rises at a rate of 1000 kV per microsecond (±50%) until its increase is interrupted by puncture of, or flashover across, the object under test. At that time the voltage collapses to zero. The rate of voltage collapse or the decay time of the voltage if breakdown does not occur (open circuit voltage of the lightning voltage generator) is not specified. Voltage waveform A is shown in Figure 3-2.

3.2.1.2 Voltage Waveform B - Full Wave

Waveform B is a 1.2 x 50 microsecond waveform which is the electrical industry standard for impulse dielectric tests. It rises to crest in 1.2 (±20%) microseconds and decays to half of crest amplitude in 50 (±20%) microseconds. Time to crest and decay time refer to the open circuit voltage of the lightning voltage generator, and assume that the waveform is not limited by puncture or flashover of the object under test. This waveform is shown on Figure 3-2.

3.2.2 Current Waveforms

It is difficult to reproduce a severe lightning flash by laboratory simulation because of inherent facility limitations. Accordingly, for determining the effects of lightning currents and for laboratory qualification testing of vehicle hardware, an idealized representation of the components of a severe lightning flash incorporating the important aspects of both positive and negative flashes has been defined and is shown on Figure 3-3.

For qualification testing, there are four components, A, B, C, and D, used for determination of direct effects and test waveform E used for determination of indirect effects. Components A, B, C, and D each simulate a different characteristic of the current in a natural lightning flash and are shown on Figure 3-3. They are applied individually or as a composite of two or more components together in one test. There are very few cases in which all four components must be applied in one test on the same test object. Rise time or rate of change of current has little effect on physical damage, and accordingly has not been specified in these components. Current waveform E, also shown on Figure 3-3, is intended to determine indirect effects. When evaluating indirect effects, rate of change of current is important and is specified.

The tests in which these waveforms are applied are presented in Table 1. The objectives of each test along with setup, measurement, and data requirements are described in Section 4.0.

3.2.2.1 Component A - Initial High Peak Current

This component simulates the first return stroke and is characterized by a peak amplitude of 200 kA (±10%) and an action integral ($\int i^2 dt$) of 2 x 10^6 amp^2-seconds (±20%) with a total time duration not exceeding 500 microseconds.

The actual waveshape of this component is purposely left undefined, because in laboratory simulation the waveshape is strongly influenced by the type of surge generator used and the characteristics of the device under test. Natural lightning currents are unidirectional, but for laboratory simulation this component may be either unidirectional or oscillatory.

3.2.2.2 Component B - Intermediate Current

This component simulates the intermediate phase of a lightning flash in which currents of several thousand amperes flow for times on the order of several milliseconds. It is characterized by a current surge with an average current of 2 kA (±10%) flowing for a maximum duration of 5 milliseconds and a maximum charge transfer of 10 coulombs. The waveform should be unidirectional, e.g. rectangular, exponential or linearly decaying.

3.2.2.3 Component C - Continuing Current

Component C simulates the continuing current that flows during the lightning flash and transfers most of the electrical charge. This component must transfer a charge of 200 coulombs (±20%) in a time of between 0.25 and 1 second. This implies current amplitudes of between 200 and 800 amperes. The waveform should be unidirectional, e.g. rectangular, exponential or linearly decaying.

3.2.2.4 Component D - Restrike Current

Component D simulates a subsequent high peak current. It is characterized by a peak amplitude of 100 kA (±10%) and an action integral of 0.25 x 10^6 ampere^2-second (±20%).

3.2.2.5 Current Waveform E - Fast Rate of Rise Stroke Test for Full-Size Hardware

Current waveform E simulates a full-scale fast rate of rise stroke for testing vehicle hardware which at full scale would be 200 kA at 100 kA/µs. The peak amplitude of the derivative of this waveform must be at least 25 kA per microsecond for at least 0.5 microsecond, as shown in Figure 3-3. Current waveform E has a minimum amplitude of 50 kA. An amplitude of 50 kA is used to enable testing of typical aircraft components with conventional laboratory lightning current generators. The action integral, fall time, and the rate of fall are not specified. If desired and feasible, components A or D may be applied with a 25 kA per microsecond rate of rise for at least 0.5 microsecond and the direct and indirect effects evaluation conducted simultaneously.

3.3 Waveform Descriptions for Engineering Tests

3.3.1 Purpose

Lightning voltage and current waveforms described in the following paragraphs have been developed for engineering design and analysis.

The tests in which these waveforms are applied are presented in Table 2. The objectives of each test, along with setup, measurement and data requirements are described in Section 4.0.

3.3.2 Voltage Waveforms

During tests on model vehicles to determine possible attachment points the length of gap used between the electrode simulating the approaching leader and the vehicle depends upon the model scale factor. During such tests it is desirable to allow the streamers from the model sufficient time to develop. Accordingly, for model tests it is necessary to standardize the time at which breakdown occurs, even though the rate of rise of voltage is different for different tests.

It has been determined in laboratory testing that the results of attachment point testing are influenced by the voltage waveform. Fast rising waveforms (on the order of a few microseconds) produce a relatively few number of attach points, usually to the apparent high field regions on the model and all such attach points are classified as Zone 1. Fast rising waveforms have been used for practically all aircraft model attach points tests in the U.S. Slow front waveforms (on the order of hundreds of microseconds) produce a greater spread of attach points, possibly including attachments to low field regions. Therefore the test data must be analyzed by appropriate statistical methods in defining Zone 1 regions.

Two high voltage waveforms are described in the following paragraphs and shown on Figure 3-4. The first is a fast waveform which is to be used for what will be termed "fast front model tests." The second waveform is a slow rising waveform which will be employed for "slow front model tests."

3.3.2.1 Voltage Waveform C - Fast Front Model Tests

This is a chopped voltage waveform in which flashover of the gap between the model under test and the test electrodes occurs at 2 microseconds (±50%). The amplitude of the voltage at time of flashover and the rate of rise of voltage prior to breakdown are not specified. The waveform is shown on Figure 3.4.

3.3.2.2 Voltage Waveform D - Slow Front Model Tests

The slow fronted waveform has a rise time between 50 and 250 microseconds so as to allow time for streamers from the model to develop. It should give a higher strike rate to the low probability regions than otherwise might have been expected.

3.3.3 Current Waveforms

Current waveform components F and G, shown on Figure 3-5, are intended to determine indirect effects on very large hardware and full size vehicles. These waveforms are specified at reduced amplitudes to overcome inherent full vehicle test circuit limitations and also to allow testing at non-destructive levels to be made on operational vehicles at non-destructive levels. Scaling will depend on the nature of the coupling process as detailed in the following paragraphs.

3.3.3.1 Test Waveform F - Reduced Amplitude Unidirectional Waveform

Component F simulates, at a low current level, both the rise time and decay time of the return stroke current peak of the lightning flash. It has a rise time of 2 microseconds (±20%), a decay time to half amplitude of 50 microseconds (±20%) and a minimum amplitude of 250 amperes. Indirect effects measurements made with this component must be extrapolated to the full lightning current amplitude of 200 kA.

3.3.3.2 Test Waveforms G_1 and G_2 - Damped Oscillatory Waveforms

Fast rate of rise current waveforms and higher amplitude waveforms may often be usefully employed for indirect effects testing. For indirect effects dependent upon resistive or diffusion flux effects (i.e. not aperture coupling) a low frequency oscillatory current - waveform G_1, in which the period (1/f) is long compared with the diffusion time, should be used. This requires a frequency, f, of 2.5 kilohertz or lower (i.e. the duration of each half-cycle is equal to or greater than 200 μs). Where resistive or diffusion effects are measured, the scaling should be in terms of the peak current, with full scale being 200 kA.

For indirect effects dependent upon aperture coupling the high frequency current, waveform G_2 should be used. The maximum frequency of waveform G_2 should be no higher than approximately 300 Khz or 1/10 of the lowest natural resonant frequency of the aircraft/return circuit, whichever is lower. Where aperture-coupled effects are measured the scaling should be in terms of rate-of-rise (di/dt), with full scale being 100 kA/μs.

When testing composite structures with waveform G_2, resistive and diffusion flux induced voltages may occur as well as aperture coupled voltages, and results should be scaled both to 200 kA and to 100 kA/μs.

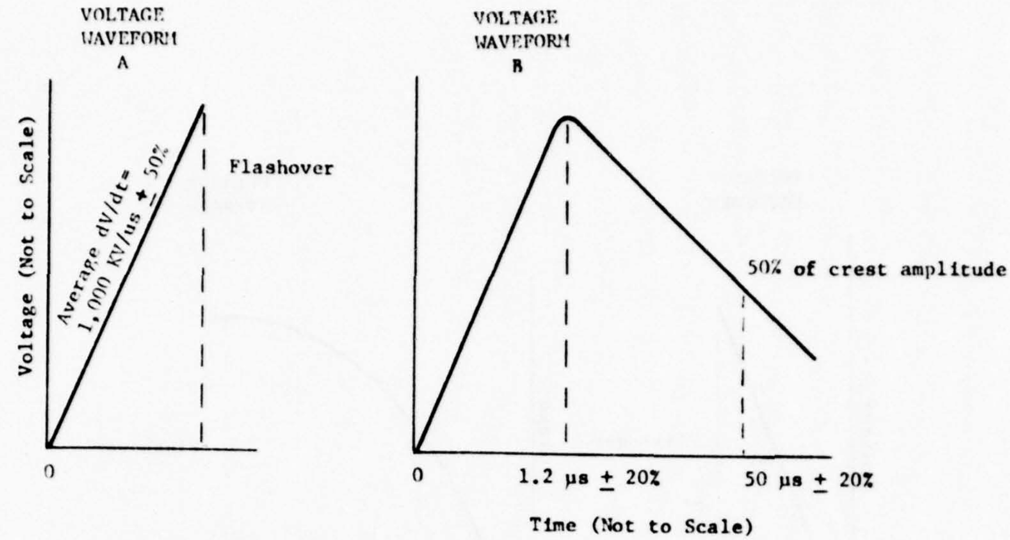


Figure 3-2 Idealized High-voltage test waveforms for qualification testing.

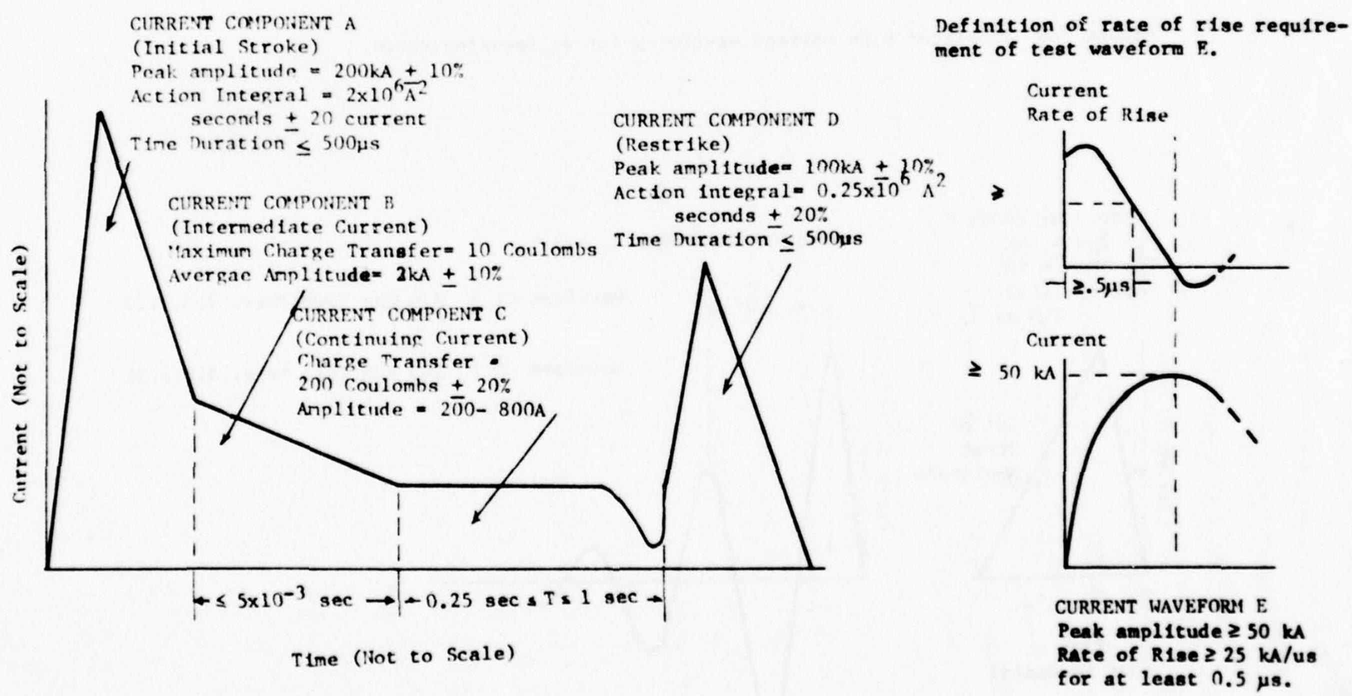


Figure 3-3 Idealized current test waveform components for qualification testing.

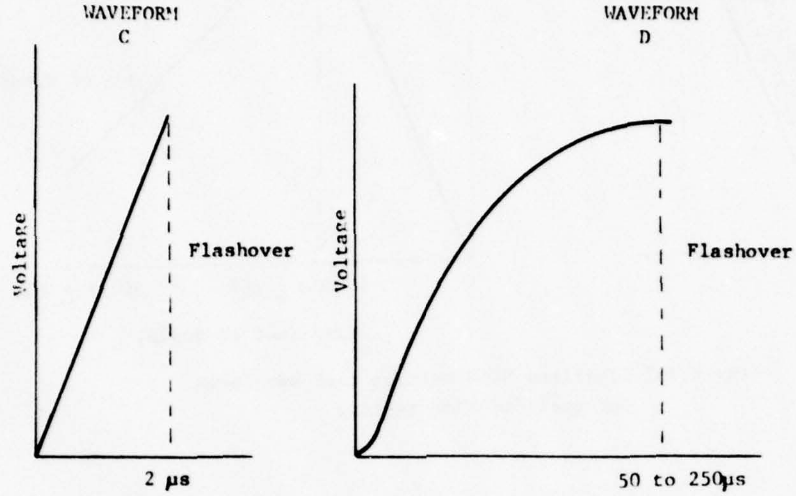


Figure 3-4 Idealized high voltage waveforms for engineering tests.

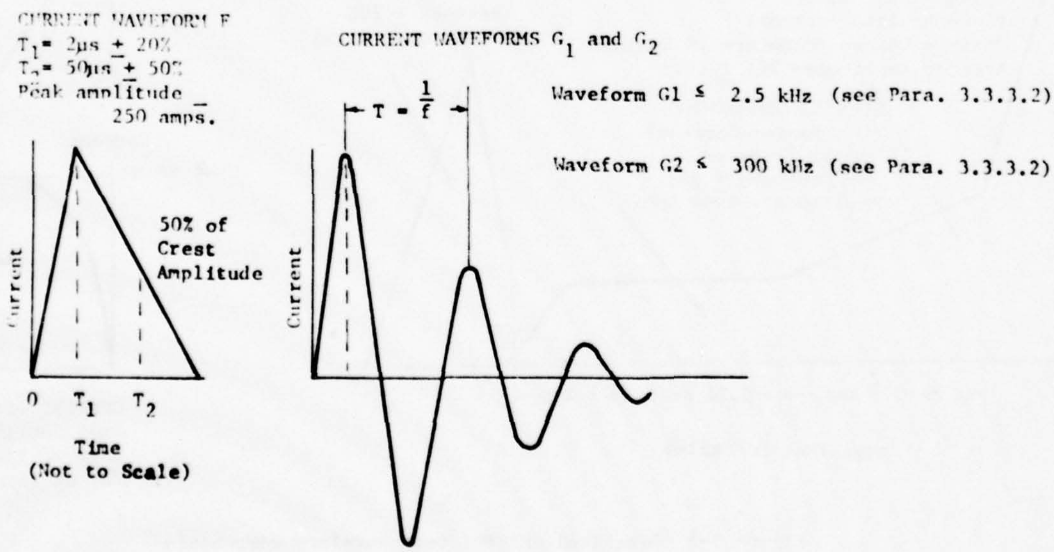


Figure 3-5 Idealized current waveforms for engineering tests. (Note: Peak amplitudes are not the same.)

Table 1

Application of Waveforms for Qualification Tests

Test	Zone	Voltage Waveforms A	Voltage Waveforms B	Voltage Waveforms D	Current Waveforms/Components A	B	C	D	E	Test Technique Para. No.
Full size hardware attachment point	1A,B	X		X						4.1.1
Direct effects - structural	1A				X	X				4.1.2, 4.1.2.2.1
"	1B				X	X	X	X		4.1.2, 4.1.2.2.2
"	2A					X		X		4.1.2, 4.1.2.2.3
"	2B					X	X	X		4.1.2, 4.1.2.2.4
"	3				X		X			4.1.2, 4.1.2.2.5
Direct effects - combustible vapor ignition	Same current components as for structural tests									4.1.3
Direct effects - streamers			X							4.1.4
Indirect effects - external electrical hardware									X[3]	4.1.5

Note 1. Use average current of 2 kA ± 10% for a dwell time less than 5 milliseconds measured in Test 4.2.2 up to a maximum of 5 milliseconds

Note 2. Use average current of 400 amp for dwell time in excess of 5 msec as determined by engineering tests.

Note 3. Indirect effects shoud also be measured with current components A, B, C, D as appropriate to the test zone

Note 4. The appropriate fraction of component "C" expected for the location and surface finish.

Table 2

Application of Waveforms for Engineering Tests

Test	Zone	Voltage Waveforms C	Voltage Waveforms D	Current Waveforms/Components C	E	F	G_1	G_2	Test Technique Para. No.
Model aircraft lightning attachment point test									
Fast front		X							4.2.1
Slow front			X						4.2.1
Full size hardware attachment test	2A			X	X				4.2.2
Indirect effects - complete						X or	X +	X	4.2.3

4.0 TEST TECHNIQUES

The simulated lightning waveforms and components to be used for qualification testing are presented in Table 1. This table gives the current components that will flow through an aircraft structure or specimen in each zone. In some cases, however, not all of the current components specified in the table will contribute significantly to the failure mechanism. Therefore, in principle, the non-contributing component(s) can be omitted from the test. If components are to be omitted from a test for this reason, the proposed test plan should be agreed upon with the cognizant regulatory authority.

Table 2 presents waveforms suggested for engineering tests. The objective of each qualification or engineering test, setup and measurement details and data requirements are described in the following paragraphs.

4.1 Qualification Tests

4.1.1 Full Size Hardware Attachment Point Tests - Zone 1

4.1.1.1 Objective

This attachment point test will be conducted on full size structures that include dielectric surfaces to determine the detailed attachment points on the external surface, and if the surface is nonmetallic, the path taken by the lightning arc in reaching a metallic structure.

4.1.1.2 Waveforms

Test voltage waveform A should be applied between the electrode and the grounded test object. In the case of test objects having particularly vulnerable or flight-critical components it may be advisable to repeat the tests using waveform D as a confirmatory test.

4.1.1.3 Test Setup

The test object should be a full-scale production line hardware component or a representative prototype, since minor changes from design samples or prototypes may change the lightning test results. All conducting objects within or on nonmetallic hardware that are normally connected to the vehicle when installed in the aircraft should be electrically connected to ground (the return side of the lightning generator). Surrounding external metallic vehicle structure should be simulated and attached to the test object to make the entire test object look as much like the actual vehicle region under test as possible.

The test electrode to which test voltage is applied should be positioned so that its tip is 1 meter away from the nearest surface of the test object. Dimensions of the test electrode are not critical. Generally, model tests or field experience will have indicated that lightning flashes can approach the object under test from several different directions. If so, the tests should be repeated with the high voltage electrode oriented to create strokes to the object from these different directions.

If the test object is so small that a 1-meter gap permits strokes to miss the test object, or if a 1-meter gap is inappropriate for other reasons, shorter or longer gaps may be used. Multiple flashovers should be applied from each electrode position. Tests may be commenced with either positive or negative polarity. If test electrode positions are found from which the simulated lightning flashovers do not contact the test piece, or do not puncture it if it is nonmetallic, the tests from these same electrode positions should be repeated using the opposite polarity.

4.1.1.4 Measurements and Data Requirements

Measurements that should be taken during these tests include the following:

a. Test Voltage and Amplitude Waveform. The voltage applied to the gap should be measured. Photographs of the voltage waveform should be taken to establish that waveform A is in fact being applied. Voltage measurements should be made of each test voltage waveform applied since breakdown paths, and hence the test voltage, may change. Particurlar attention should be given to assuring that the gap flashes over on the wavefront. If a flashover occurs on the wave tail, the test should be repeated with the generator set to provide a higher voltage or the test electrode positioned closer to the test object so as to produce flashover on the wavefront.

b. Attachment Points and/or Breakdown Paths The voltage generators used for these tests are high impedance devices. The test current may be much less than natural lightning currents. Consequently, they will produce much less damage to the test object than a natural lightning flash, even though the breakdown will follow the path a full-scale lightning stroke current would follow. Occasionally a diligent search will be required to find the attachment point on metals or the breakdown path through nonmetallic surfaces. These attachment points or breakdown paths should be looked for after each test and marked, when found, with masking tape or crayon markings to prevent confusion with further test results.

4.1.2 Direct Effects - Structural

4.1.2.1 Objective

These tests determine the direct effects which lightning currents may produce in structures.

4.1.2.2 Waveforms

Simulated lightning current waveform components should be applied, depending on the vehicle zone of the test object, as follows:

4.1.2.2.1 Zone 1A

Waveform components A and B should be applied.

4.1.2.2.2 Zone 1B

Waveform components A, B, C, and D should be applied in that order, but not necessarily as one continuous discharge.

4.1.2.2.3 Zone 2A

Although Zone 2A is a swept stroke zone, static tests can be conducted once the attachment points and dwell times have been determined. Current components D, B, and C should be applied in that order as appropriate to the following discussion.

High peak current restrikes typically produce re-attachment of the arc at a new point. Therefore, current component D is applied first. The dwell time for components B and C in Zone 2A may be determined from swept stroke tests as described in Paragraph 4.2.2 or, alternatively, a worst case dwell time of 50 milliseconds may be assumed without conducting swept stroke tests. The timing mechanism of the generator producing component B should be set to allow current to flow into the test object (at any single point) for the maximum dwell time at that point as determined from the dwell point tests. If the measured dwell time is greater than 5 milliseconds or if a 50 millisecond dwell time has been assumed, the component B current should be reduced to 400 amperes (component C) for the dwell time in excess of 5 milliseconds. If the measured dwell time is less than 5 milliseconds, component B should be applied for the length of time measured, down to a minimum of 1 millisecond.

4.1.2.2.4 Zone 2B

Current components B, C and D should be applied in that order.

4.1.2.2.5 Zone 3

Current components A and C should be applied in that order to test objects in Zone 3. The test currents should be conducted into and out of the test object in a manner similar to the way lightning currents would be conducted through the aircraft.

4.1.2.3 Test Setup

4.1.2.3.1 Test Electrode and Gap

The test currents are delivered from a test electrode positioned adjacent to the test object. The test object is connected to the return side of the generator(s) so that test current can flow through the object in a realistic manner.

CAUTION: There may be interactions between the arc and current carrying conductors. Care must be taken to assure that these interactions do not influence the test results.

The electrode material should be a good electrical conductor with ability to resist the erosion produced by the test currents involved. Yellow brass, steel, tungsten and carbon are suitable electrode materials. The shape of the electrode is usually a rounded rod firmly affixed to the generator output terminal and spaced at a fixed distance above the surface of the test object.

The polarity of components A and D can be either positive or negative. The polarity of the generators used to produce components B and C should be set so that the electrode is negative with respect to the test object, because greater damage is generally produced when the test object is at positive polarity with respect to the test electrode.

4.1.2.4 Measurements and Data Requirements

Measurements for these tests include test current amplitude(s) and waveform(s). Initial stroke, restrike and intermediate current components may be measured with noninductive resistive shunts, current transformers, or Rogowski coils. Continuing currents may be measured with resistive shunts. The output of each of these devices should be measured and recorded.

NOTE: Indirect effects measurements are frequently required for external electrical hardware, as specified in Paragraph 4.1.6. If desired, some of these measurements can be made during the direct effects tests.

Since the condition of the test object or other parts of the test circuit may affect the test current(s) applied, measurements of these parameters should be made during each test applied, and the details of the test setup recorded for each test.

4.1.3 Direct Effects - Combustible Vapor Ignition Via Skin or Component Puncture, Hot Spots or Arcing

4.1.3.1 Objective

The objective of these tests is to ascertain the possibility of combustible vapor ignition as a result of skin or component puncture, hot spot formation, or arcing in or near fuel systems or other regions where combustible vapors may exist.

CAUTION: These tests simulate the possible direct effects which may cause ignition. Ignition of combustible vapors may also be caused by lightning indirect effects such as induced voltages in fuel probe wiring, etc.

If a blunt electrode is used with a very small gap, the gas pressure and shock wave effects in the confined area may cause more physical damage than would otherwise be produced. The electrode should be rounded to allow relief of the pressure formed by the discharge.

For multiple component tests, the test electrode should be placed as far from the test object surface as the driving voltage of the intermediate component B or continuing current component C will allow. A gap spacing of at least 50 mm is desirable but a lesser gap of at least 10 mm is required which will result in more conservative data. When components B or C are preceded by the high peak current component A, the high driving voltage of this generator initiates the arc and subsequent components B and/or C follow the established arc even though driven by a much lower voltage.

4.1.3.2 Waveforms

The same test current waveforms should be applied as are specified for structural damage tests in Paragraph 4.1.2.2.

4.1.3.3 Test Setup

Test setup requirements are the same as those described in Paragraph 4.1.2.3 for structural damage tests, with the following additional considerations:

If a complete fuel tank is not available or impractical for test, a sample of the tank skin or other specimen representative of the actual structural configuration (including joints, fasteners and substructures, attachment hardware, as well as internal fuel tank fixtures) should be installed on a light-tight opening or chamber. Photography is the preferred technique for detecting sparking. If photography can be employed, the chamber should be fitted with an array of mirrors to make any sparks visible to the camera. However, for regions where possible sparking activity cannot be made visible to the camera, ignition tests may be used by placing an ignitable fuel-air mixture inside the tank. This can be a mixture of propane and air (e.g., for propane: a 1.2 stoichiometric mixture) or vaporized samples of the appropriate fuel mixed with air. Verification of the combustibility of the mixture should be obtained by ignition with a spark or corona ignition source introduced into the test chamber immediately after each lightning test in which no ignition occurred. If the combustible mixture was not ignitable by this artificial source, the lightning test must be considered invalid and repeated with a new mixture until either the lightning test or artificial ignition source ignites the fuel.

4.1.3.4 Measurements and Data Requirements

The same test current measurements should be made as are specified for structural damage tests in Paragraph 4.1.2.4.

The presence of an ignition source should be determined by photography of possible sparking. For this purpose a camera is placed in the test chamber and the shutter left open during the test. Experience indicates that ASA 3000 speed film exposed at f4.7 is satisfactory. All light to the chamber interior must be excluded. Any light indications on the film due to internal sparking after test should be taken as an indication of sparking sufficient to ignite a combustible mixture.

CAUTION: This method of determining the possibility of sparking should be utilized only if certainty exists that all locations where sparking might exist are visible to the camera.

More specialized instrumentation may be added if additional information such as skin surface temperatures, pressure rises, or flame front propagation velocities are desired.

4.1.4 Direct Effects - Streamers

4.1.4.1 Objective

Electrical streamers initiated by a high voltage field represent a possible ignition source for combustible vapors. The objective of this test is to determine if such streamers may be produced in regions where such vapors exist.

4.1.4.2 Waveforms

Test voltage waveform B should be applied for this test. The crest voltage should be sufficient to produce streamering, but not sufficient to cause flashover in the high-voltage gap. Generally, this will require that the average electric field gradient between the electrodes be at least 5 kV/cm.

4.1.4.3 Test Setup

The test object should be mounted in a fixture representative of the surrounding region of the airframe and be subjected to the high-voltage waveform. The voltage may be applied either by (1) grounding the test object and arranging the high-voltage test electrode sufficiently close to the test object to create the required field at the test voltage level applied or (2) connecting the test object to the high-voltage output of the generator and arranging the test object in proximity to a ground plane or other ground electrode that is connected to the ground or low side of the generator. In either case the low voltage side of the generator should be grounded. Either arrangement can provide the necessary electric field at the test object aperture. The test object should be at positive polarity with respect to ground, since this polarity usually provides the most profuse streamering.

4.1.4.4 Measurements and Data Requirements

Measurements should include test voltage waveform and amplitude, and degree and location of streamering. The presence of streamering at locations where combustible vapors are known to exist is considered an ignition source. The presence of streamering can best be determined with photography of the test object while in a darkened area. If the presence of streamers is questionable, the test should be run with a combustible mixture actually present in the test object to determine if ignition occurs, but care should be taken to ensure that the test arrangement simulates relevant operational (i.e., in-flight) characteristics.

4.1.5 Direct Effects - External Electrical Hardware

4.1.5.1 Objective

The object of this test is to determine the amount of physical damage which may be experienced by externally mounted electrical components, such as pitot tubes, antennas, navigation lights, etc. when directly struck by lightning.

4.1.5.2 Waveforms, Test Setup, and Measurements and Data Requirements

Same as for structures test as described in Paragraph 4.1.2.

4.1.6 Indirect Effects - External Electrical Hardware

4.1.6.1 Objective

The objective of this test is to determine the magnitude of indirect effects that occur when lightning strikes externally mounted electrical hardware, such as antennas, electrically heated pitot tubes, or navigation lights. For such hardware the indirect effects include conducted currents and surge voltages, and induced voltages. These currents and voltages may then be conducted via electrical circuits to other systems in the vehicle. Therefore, during the direct effects tests of electrical hardware mounted within Zones 1 or 2, measurements should be made of the voltage appearing at all electrical circuit terminals of the component. In addition, a fast rate of rise test should be conducted for evaluation of magnetically induced effects.

4.1.6.2 Waveforms

Current components A through D used for evaluation of direct effects are also used for evaluation of indirect effects, particularly those relating to the diffusion or flow of current through resistance. The specific waveforms to be used are the same as those specified in Paragraph 4.1.2. In addition, the fast rate of change current waveform E should be applied for evaluation of magnetically induced effects.

Indirect effects measured as a result of this waveform must be extrapolated as follows. Induced voltages dependent upon resistive or diffusion flux should be extrapolated linearly to a peak current of 200 kA.

Induced voltages dependent upon aperture coupling should be extrapolated linearly to a peak rate-of-rise of 100 kA/μs.

4.1.6.3 Test Setup

The test object should be mounted on a shielded test chamber so that access to its electrical connector(s) can be obtained in an area relatively free from extraneous electromagnetic fields. This is necessary to prevent electromagnetic interference originating in the lightning test circuit from interfering with measurement of voltages induced in the test object itself. The test object should be fastened to the test chamber in a manner similar to the way it is mounted on the aircraft, since normal bonding impedances may contribute to the voltages induced in circuits. If the shielded enclosure is large enough, the measurement/recording equipment may be contained within it. If not, a suitable shielded instrument cable may be used to transfer the induced voltage signal from the shielded enclosure to the equipment. In this case, the equipment should be located so as not to experience interference.

The test electrode should be positioned so as to inject simulated lightning current into the test object at the probable attachment point(s) expected from natural lightning. For tests run concurrently with direct effects tests on the same test object, this should be an arc-entry (flashover from test electrode to test object); but for tests made only to determine the indirect effects, hard-wired connections can be made between the generator output and test object. This is appropriate especially if it is desired to minimize physical damage to the test object. The test object should be grounded via the shielded enclosure so that simulated lightning current flows from the test object to the shielded enclosure in a manner representative of the actual installation.

4.1.6.4 Measurements and Data Requirements

Measurements should include test current amplitude(s) and waveform(s) as specified for the direct effects tests utilizing the same waveforms in Paragraph 4.1.2. In addition, measurements should be made of conducted and induced voltages at the terminals of electrical circuits in the test object.

Measurement of the voltages appearing at the electrical terminals of the test object should be made with a suitable recording instrument having a bandwidth of at least 30 megahertz.

In some cases it is appropriate to make measurements of the voltage between two terminals, as well as of the voltage between either terminal and ground. Since the amount of induced voltage originating in the test object which can enter systems such as a power bus or an antenna coupler depends partly on the impedances of these items, these impedances should be simulated and connected across the electrical terminals of the test object where the induced voltage is being measured.

The resistance, inductance and capacitance of the load impedance should be included. A typical test and measurement circuit is shown in Figure 4.1.

CAUTION: Interference-free operation of the voltage measurement system should be verified.

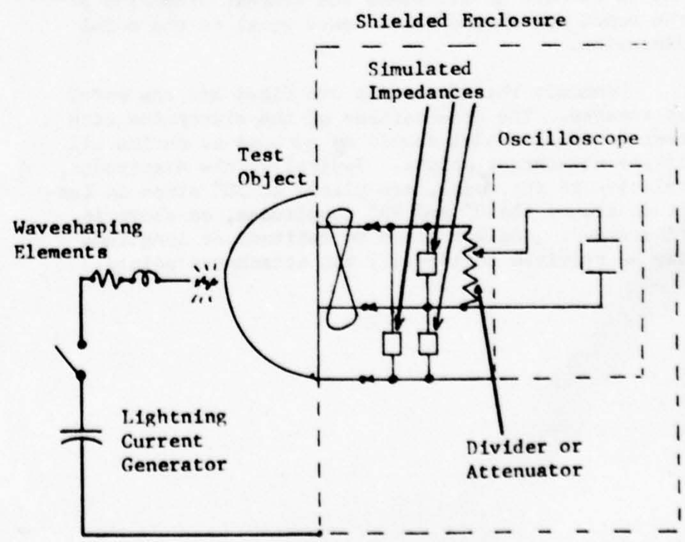


Figure 4-1 Essential elements of electrical hardware indirect effects, test and measurement circuit.

4.2 Engineering Tests

4.2.1 Model Aircraft Lightning Attachment Point Test

4.2.1.1 Objective

The objective of the model test is to determine the places on the vehicle where direct lightning strikes are likely to attach.

4.2.1.2 Waveforms

If it is desired to determine the places on the aircraft where lightning strikes are most probable, then voltage waveform C may be utilized. If it is desired, in addition, to identify other surfaces where strikes may also occur on rare occasion, voltage waveform D may be utilized. The longer rise-time of waveform D allows development of streamers and attachment points in regions of lower field intensity (in addition to those of high intensity at surfaces of high strike probability.

4.2.1.3 Test Setup

Tests on small-scale models are helpful for determining attachment zones. In some cases, tests on models must be supplemented by other means to determine exact attachment zones or points. This is particularly true of aircraft involving large amounts of nonmetallic structural materials.

An accurate model of the vehicle exterior from 1/30 to 1/10 full scale should be constructed. The various possible vehicle configurations should also be modeled. Conducting surfaces on the aircraft should be represented by conductive surfaces on the model, and vice versa.

The model is then positioned on insulators between the electrodes of a rod-rod gap or the electrode and a ground plane of a rod-plane gap. The length of the upper gap should be at least 1.5 times the longest dimension of the model. The direction of approach becomes less controllable at much higher ratios and the stroke may even miss the model. The lower gap, may be as much as 2.5 times the longest dimension of the model and should be at least equal to the model dimension.

Commonly the electrodes are fixed and the model is rotated. The orientations of the electrodes with respect to the model should be such as to define all likely attachment points. Typically, the electrodes, relative to the model, are placed at 30° steps in latitude around the 0° and 90° longitudes, as shown in Figure 4-2. Smaller steps in latitude or longitude may be required to identify all attachment points.

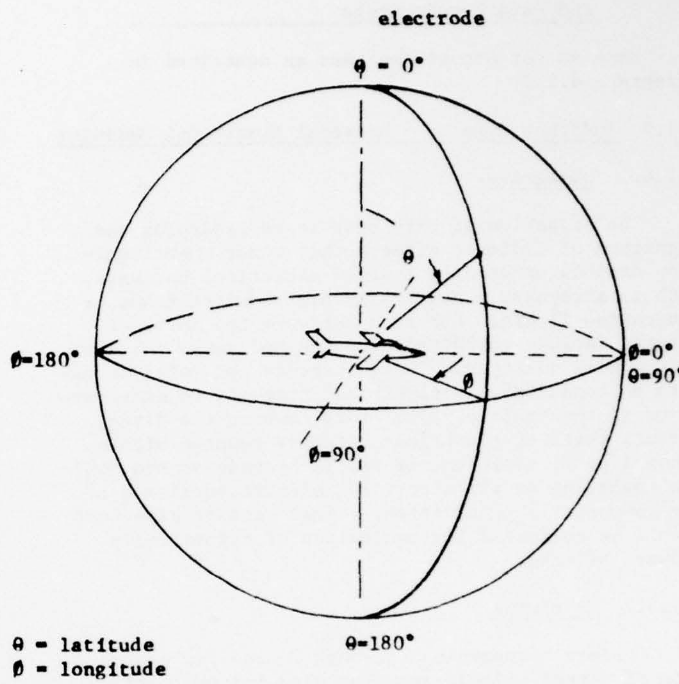


Figure 4-2 Aircraft coordinate system.

If rotation of the model significantly changes the gap lengths, it may be necessary to reposition the electrode. Typically three to ten shots are taken with the aircraft in each orientation to simulate lightning flashes approaching from different directions. Photographs, preferably with two cameras at right angles to each other, should be taken of each shot in order to determine the attachment points. The upper electrode should be positive with respect to ground and/or the lower electrode.

4.2.2 Full-Size Hardware Attachment Point Test - Zone 2

4.2.2.1 Objective

The mechanism of arc attachment in Zone 2 regions is fundamentally different from that in Zone 1. The basic mechanism of attachment is shown on Figure 4-3. The arc first attaches to point 1 and then, viewing the test object as stationary, is swept back along the surface to point 2. When the heel of the arc is above point 2 the voltage drop at the arc-metal interface is sufficiently high to cause flashover of the air gap and puncture of the surface finish at point 2 causing it to re-attach there.

The arc will again be blown back along the surface until the voltage along the arc channel and arc-metal interface is sufficient to cause flashover and attachment to another point. The voltage at which each new attachment will occur depends strongly upon the surface finish of the object under test. The voltage available to cause puncture depends upon the current flowing in the arc and the degree of ionization in its channel. There is an inductive voltage rise along the arc as rapidly changing currents flow through it. There will also be a resistive voltage rise produced by the flow of current. The inductive voltage rise as well as the resistive rise can be quite significant when a lightning restrike occurs at some point in the flash.

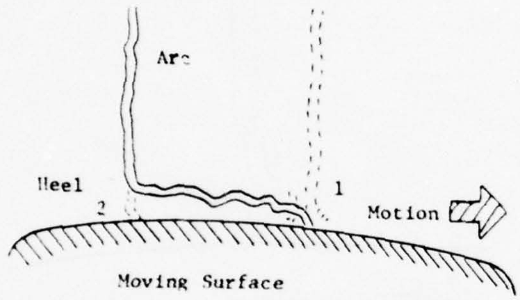


Figure 4-3 Basic mechanism of swept stroke attachment.

In addition, if the flash is discontinuous for a brief period a very high voltage is available prior to flow of the next current component. Because the channel remains hot and may contain residual ionized particles, this voltage stress is greatest along it and subsequent current components are likely to flow along the same channel. Such a voltage may well be higher than voltages created by currents flowing in the channel and may cause re-attachment to metallic surfaces or puncture of nonmetallic surfaces or dielectric coatings.

The time during which an arc may remain attached to any single point (dwell time) is a function of the lightning flash and surface characteristics which govern reattachment to the next point. The dwell time is also a function of aircraft speed.

Swept stroke attachment point and dwell time phenomena are therefore of interest for two main reasons. First, if there is an intervening nonmetallic surface along the path over which the arc may be swept, the swept stroke phenomena may determine whether the nonmetallic surface will be punctured or whether the arc will pass harmlessly across it to the next metallic surface.

Second, the dwell time of an arc on a metallic surface is a factor in determining if sufficient heating may occur at a dwell point to burn a hole or form a hot spot capable of igniting combustible mixtures or causing other damage. Thus, over a fuel tank it is particularly important that the arc move freely, in order that the metal skin of the tank not be heated or burned to a point that fuel vapors are ignited.

The objectives of attachment studies in Zone 2 are then:

<u>For metallic curfaces</u>
(including conventional painted or treated surfaces):
To determine possible attachment points and associated dwell times.

<u>For nonmetallic surfaces</u>
(including metallic surfaces with high dielectric strength coatings):
To determine if punctures may occur.

4.2.2.2 <u>Waveforms</u>

4.2.2.2.1 <u>Metallic Surfaces</u>

To determine arc dwell times on metallic surfaces, including conventional painted or treated surfaces, it is necessary to simulate the continuing current component of the lightning flash. Thus the simulated continuing current should be in accordance with current component C.

The current generator driving voltage must be sufficient to maintain an arc length that moves freely along the surface of the test object. The test electrode should be far enough above the surface so as not to influence the arc attachment to the test surface. If the technique of Figure 4-3 is used, the electrode should be a rod parallel to the air stream and approximately parallel to the test object.

A restrike may be added to the continuing current after initiation to determine whether a restrike with its associated high current amplitude would cause re-attachment to points other than those to which the continuing current arc would re-attach. If a restrike is used it is most appropriate that it be the fast rate of change of current waveform shown as current waveform E on Figure 3-3.

4.2.2.2.2 <u>Nonmetallic Surfaces</u>

To determine whether it is possible for dielectric punctures or reattachments to occur on nonmetallic surfaces or coating materials, including metallic surfaces with high dielectric strength coatings, it is necessary to simulate the high-voltage characteristics of the arc. High voltages are caused by (1) current restrikes in an ionized channel, or (2) voltage buildup along a deionized channel. These characteristics are simulated by a test in which a restrike is applied along a channel previously established by a continuing current. The restrike must be initiated by a voltage rate of rise of 1000 kV/μs or faster and must discharge a high rate of rise current stroke in accordance with current waveform E. This restrike must not be applied until the continuing current has decayed to near zero (a nearly deionized state) as shown in Figure 4-4.

Several tests should be applied with the continuing current duration and restrikes applied according to different times, T, in order to produce worst-case exposures of the surface and underlying elements to voltage stress.

The amplitude of the continuing current is not critical and may be lower or higher than that of current component C. Other aspects of this test are as described in Paragraph 4.2.2.2.1.

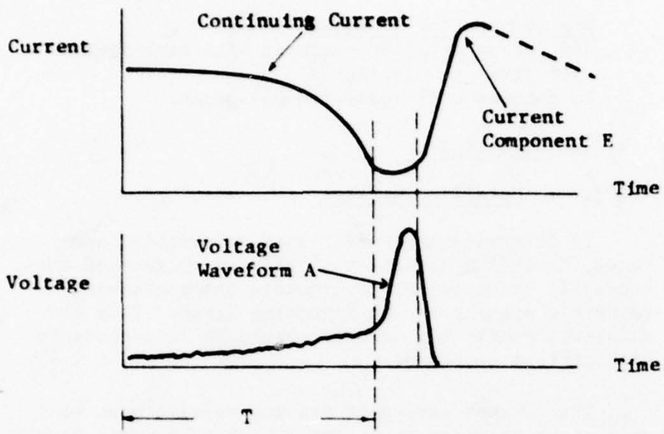


Figure 4-4 Swept stroke waveforms for tests of nonmetallic surfaces.

4.2.2.3 Test Setup

Two basic methods have been used to simulate the swept stroke mechanism. One of these involves use of a wind stream to move the arc relative to a stationary test surface as shown in Figure 4-5. The other method involves movement of the test surface relative to a stationary arc as shown in Figure 4-6. Other methods may also be satisfactory if they adequately represent the in-flight interaction between the arc and the aircraft surface. Relative velocity should include but not be limited to the minimum in-flight velocity of the vehical, which is when the dwell time condition is most critical.

The test electrode should be far enough above the surface so as not to influence the arc attachment to the test surface. If the technique of Figure 4-5 is used, the electrode should be a rod parallel to the air stream and approximately parallel to the test object.

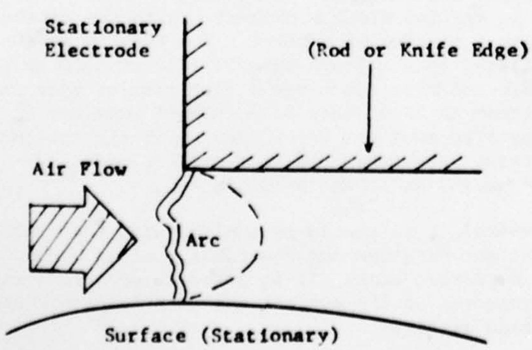


Figure 4-5 Arc moved relative to stationary test surface.

4.2.2.4 Measurements and Data Requirements

The most important measurements are those giving the attachment points, arc dwell times, breakdown paths followed, and the separation between attachment points. These are most easily determined from high speed motion picture photographs of the arc. Measurements should be made of the air flow or test object velocity and the amplitude and waveform of the current passing through the test object.

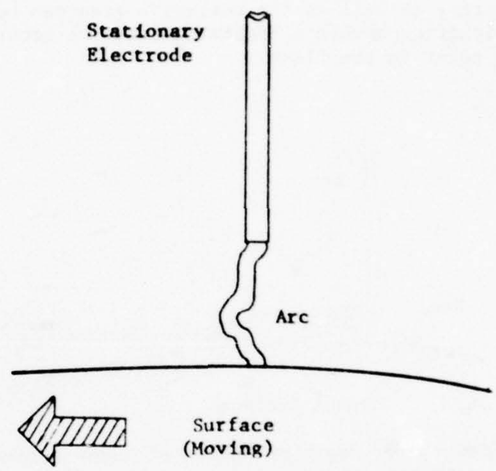


Figure 4-6 Test surface moved relative to stationary arc.

4.2.3 Indirect Effects - Complete Vehicle

4.2.3.1 Objective

The objective of this test is to measure induced voltages and currents in electrical wiring within a complete vehicle. Complete vehicle tests are intended primarily to identify circuits which may be susceptible to lightning induced effects.

4.2.3.2 Waveforms

Two techniques, utilizing different waveforms, may be utilized to perform this test. One involves application of a scaled down unidirectional waveform representative of a natural lightning stroke.

The second technique involves performance of the test with two or more damped oscillatory current waveforms, one of which (component G_2) provides the fast rate of rise characteristic of a natural lightning stroke wavefront, and the other (component G_1) provides a long duration period characteristic of natural lightning stroke duration. Induced voltages should be measured in the aircraft circuits when exposed to both waveforms and the highest induced voltages taken as the test results.

Each test is carried out by passing test currents through to the complete vehicle and measuring the induced voltages and currents. Checks are also made of aircraft systems and equipment operations where possible.

4.2.3.2.1 Unidirectional Test Waveform

Waveform F should be applied.

4.2.3.2.2 Oscillatory Waveforms

Waveforms G_1 and G_2 should be applied.

4.2.3.3 Test Setup

The test current should be applied between several representative pairs of attachment points such as nose-to-tail or wing tip-to-wing tip. Typical test setups are shown in Figure 4-7.

Attachment pairs are normally selected so as to direct current through the parts of the vehicle where circuits of interest are located.

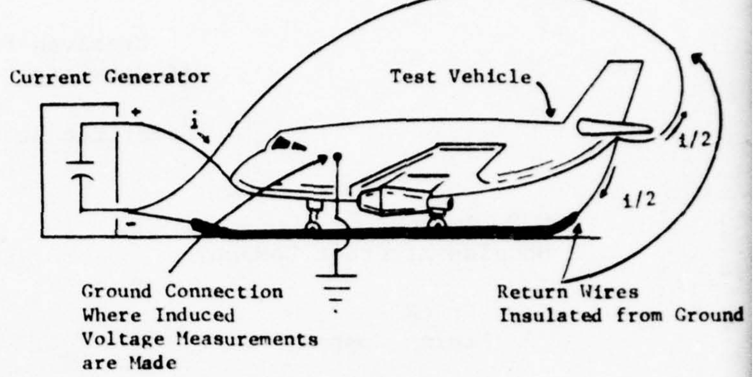
Multiple return conductors should be used to minimize test circuit inductance and proximity effects. Typical test setups are shown in Figure 4-7.

4.2.3.4 Measurements and Data Requirements

The test current amplitude, waveform, and resulting induced voltages and currents in the aircraft electrical and avionics systems should be measured.

CAUTION: Interference-free operation of the voltage measurement system should be verified.

Voltages measured during the complete vehicle tests should be extrapolated to full threat levels in the same manner as described in Para. 4.1.6.2 for indirect effects measurements in external electrical hardware. Situations such as arcing paths or nonlinear impedances exist which may result in nonlinear relationships between induced voltages and applied current. Careful study of the vehicle under test, however, can usually identify such situations. When testing fueled vehicles, care should be taken to prevent sparks across filler caps, as even low amplitude currents can cause sparking across poor bonds or joints. In doubtful situations, fuel tanks should be rendered nonflammable by nitrogen inerting.



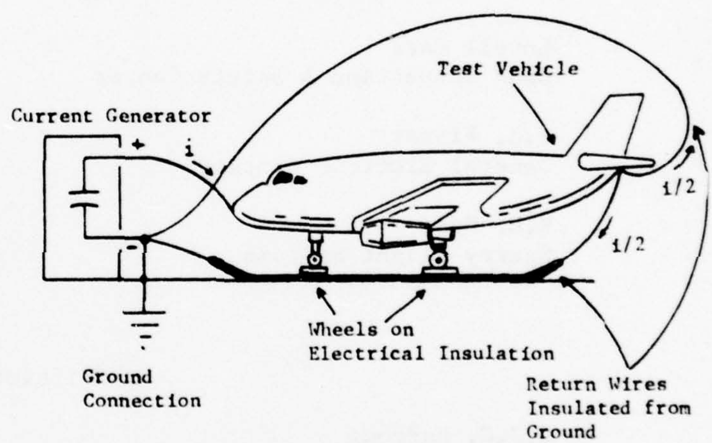


Figure 4-7. Typical setups for complete vehicle tests.

Prepared By
SAE Committee AE4-L

Committee Members:

M.P. Amason
Douglas Aircraft Company

R.O. Brick
The Boeing Company

D.W. Clifford
McDonnell Aircraft Company

G.A. DuBro
USAF Flight Dynamics Laboratory

Lovell Earl
USAF Inspection & Safety Center

F.A. Fisher
General Electric Company

R.H. Hess
Sperry Flight Systems

Dong Kim
USAF Flight Dynamics Laboratory

H. Knoller
Lockheed-California Company

C.P. Mudd
U.S. Army Aviation Systems Command

S.D. Schneider
The Boeing Company

J.R. Stahmann
PRC Systems Services Company

W.T. Walker
U.S. Naval Air Test Center

Ex Officio:

B.J.C. Burrows
UK/AEA Culham Laboratory

P.F. Little
UK/AEA Culham Laboratory

A.W. Hanson
UK/AEA Culham Laboratory

J.A. Plumer, Co-chairman
Lightning Technologies, Inc.

J.D. Robb, Co-chairman
Lightning & Transients Research Institute

FINAL PROGRAM
FEDERAL AVIATION ADMINISTRATION/FLORIDA INSTITUTE OF TECHNOLOGY
WORKSHOP ON
GROUNDING AND LIGHTNING PROTECTION

March 6-8, 1979

TUESDAY, MARCH 6

MORNING SESSION

7:30 - 8:30 REGISTRATION

8:30 - Introduction - Mr. Richard M. Cosel
Electrical Engineering
Florida Institute of Technology

8:35 - Welcome - Dr. Jerome P. Keuper, President
Florida Institute of Technology

8:40 - Opening Remarks - Mr. Cosel

8:45 - Announcements - Mr. Richard E. Enstice, Director, Continuing Education
Florida Institute of Technology

SESSION MODERATOR: Prof. Warren D. Peele
Purdue University

9:00 - RETURN STROKE LIGHTNING CHANNEL MODEL - Dr. D. Quinn, Flight Dynamics Laboratory, Wright-Patterson AFB

NON-LINEAR MODELING OF LIGHTNING RETURN STROKES - Dr. D. Strawe, Boeing Aerospace Company

ELECTRIC FIELDS IN THUNDERCLOUDS - W. P. Winn, C. B. Moore and C. R. Holmes, New Mexico Institute of Mining & Technology and L. G. Byerley, Lightning Location & Protection

10:45 - Break

11:00 - INITIAL CURRENTS ASSOCIATED WITH LIGHTNING TRIGGERED BY A ROCKET - R. B. Standler, University of Florida and C. B. Moore, New Mexico Institute of Mining & Technology

MEASUREMENTS ON NATURAL AND TRIGGERED LIGHTNING - J. Boulay and P. Laroche, Office National d'Etudes et de Recherches Aerospatiales, France

FURTHER CONSIDERATION OF BLUNT AND SHARP LIGHTNING RODS - C. Moore, New Mexico Institute of Mining & Technology and R. Standler, University of Florida

12:45 - 2:00 LUNCH

AFTERNOON SESSION

SESSION MODERATOR: Mr. Ray Barkalow
Consultant

2:00 - LIGHTNING WARNING DEVICES - Dr. R. Bent, Atlantic Scientific Corporation

GROUND EVALUATION OF LIGHTNING MONITORING SYSTEM (STORMSCOPE)
J. G. Schneider, Technology/Scientific Services, Inc. and
V. L. Mangold, Wright-Patterson AFB

3:15 - Break

3:30 - EVALUATION OF THE RYAN STORMSCOPE AS A SEVERE WEATHER AVOIDANCE SYSTEM FOR AIRCRAFT - PRELIMINARY REPORT - T.J. Seymour and Lt. R. Baum, Flight Dynamics Laboratory, Wright-Patterson AFB

LIGHTNING DETECTION AND RANGING SYSTEM (LDAR) AS A THUNDERSTORM WARNING AND LOCATION DEVICE - C. L. Lennon, Launch Systems Operation Section, NASA -KSC

A NEW APPROACH TO LIGHTNING POSITION AND TRACKING - Dr. R. Bent, Atlantic Scientific Corporation

6:30 - Cocktail Party

7:30 - Dinner

WEDNESDAY, March 7

MORNING SESSION

SESSION MODERATOR: Dr. G. Keith Huddleston
Georgia Institute of Technology

8:30 - TECHNIQUES FOR INCREASING THE LIGHTNING TOLERANCE OF THE NAVY/AIR FORCE COMBAT MANEUVERING RANGE INSTRUMENTATION SYSTEMS - J. E. Nanevicz, E. F. Vance, SRI International

LIGHTNING CURRENT TRANSFER ALONG PERIODICALLY GROUNDED PIPELINES, FENCES, CABLE TRAYS AND BURIED CABLES - J. R. Stahmann, M. W. Brooks, PRC Systems Services Company

DESIGN OF ELECTRONIC SYSTEMS TOLERANT OF POOR GROUNDING - T. H. Herring, Boeing Aerospace Company

10:15 Break

10:30 ANALYZING SURGE-PROTECTIVE DEVICES WITHIN A COMMON FRAMEWORK - B. I. Wolff, General Electric Company

PROTECTING FACILITIES AND EQUIPMENT FROM INDUCED LIGHTNING AND VOLTAGE ON THE A. C. POWER LINE - R. Odenberg, Transtector System (Paper not delivered due to illness. However, it is included in the Proceedings.)

EFFECT OF LEAD WIRE LENGTH ON PROTECTOR CLAMPING VOLTAGES - O. M. Clark, J. J. Pizzicaroli, General Semiconductor Industries Inc.

DESIGN, DEVELOPMENT AND FABRICATION OF DEVICES FOR PROTECTION OF ELECTRONIC EQUIPMENT AGAINST LIGHTNING - J.P. SIMI, Les Cables de Lyon, Bezons, France

LIGHTNING FATALITIES: CAN THEY BE PREVENTED - A brief synopsis of a paper by W. E. Cobb, Atmospheric Physics and Chemistry Laboratory, NOAA, Boulder, Colorado

12:45 - 2:00 p.m. Lunch

AFTERNOON SESSION

SESSION MODERATOR: Mr. John E. Reed
Federal Aviation Administration

2:00 - A NEW STANDARD FOR LIGHTNING QUALIFICATION TESTING OF AIRCRAFT - J. A. Plumer, Lightning Technologies, Inc.

THE APPLICATION OF NUCLEAR EMP PROTECTION TECHNOLOGY TO LIGHTNING PROTECTION PROBLEMS - T. J. Lange, The Boeing Company

SPACE SHUTTLE LIGHTNING PROTECTION - D. L. Suiter, R. D. Gadbois, R. L. Blount, NASA, Houston

3:45 - Break

4:00 - LIGHTNING PROTECTION DESIGN OF THE SPACE SHUTTLES - M. S. Amsbary, G. R. Read and B. L. Giffin, Rockwell International

AN RF COMPATIBLE LIGHTNING DIVERTER STRIP - J. Cline, J. Raney Dayton Granger Aviation, Inc., Capt. J. Dunn, USAF, Eglin AFB J. Robb, LTRI

THURSDAY, MARCH 8

MORNING SESSION

SESSION MODERATOR: Mr. John E. Reed
Federal Aviation Administration

8:30 - PROTECTION/HARDENING OF AIRCRAFT ELECTRONIC SYSTEMS AGAINST THE INDIRECT EFFECTS OF LIGHTNING - J. C. Corbin, Jr., Flight Dynamics Laboratory, Wright-Patterson AFB

IN-FLIGHT LIGHTNING CHARACTERISTICS MEASUREMENT SYSTEM - F. L. Pitts, M. E. Thomas, R.E. Campbell, R. M. Thomas, K. P. Zaepfel, NASA-Langley Research Center

IN-FLIGHT MEASUREMENTS OF NATURAL LIGHTNING CHARACTERISTICS - K. J. Maxwell, L. C. Walko, Technology/Scientific Services, Inc. and V. L. Mangold, Wright-Patterson AFB

10:15 Break

10:30 - LIGHTNING EFFECTS ON GENERAL AVIATION AIRCRAFT - J. A. Plumer, Lightning Technologies, Inc.

TEST TECHNIQUES FOR SIMULATING LIGHTNING STRIKES TO CARBON FIBRE COMPOSITE STRUCTURES - P. F. Little, A. W. Hanson, B. C. Burrows, Culham Laboratory UKAEA, England

INDUCED EFFECTS OF LIGHTNING ON AN ALL COMPOSITE AIRCRAFT - R. A. Perala, R. B. Cook, Electro Magnetic Applications, Inc. and K. M. Lee, Mission Research Corporation

DISTRIBUTION OF LIGHTNING CURRENTS - B. C. Burrows, Culham Laboratory, UKAEA, England

11:45 - Adjourn

FEDERAL AVIATION ADMINISTRATION/FLORIDA INSTITUTE OF TECHNOLOGY
WORKSHOP ON
GROUNDING AND LIGHTNING PROTECTION
ATTENDANCE ROSTER

Mr. Bill Ackerman
Lear Avia Corp.
P. O. Box 60000
Reno, NV 89506

Ms. M. S. Amsbary
Rockwell International-FC 50
12214 Lakewood Blvd.
Downey, CA 90241

Mr. Herman D. Anderson
Defense Electronics Supply Center
1507 Wilmington Pike
Dayton, OH 45444

Mr. Charles J. Andrasco
FAA
ARO-650
Washington, DC

Mr. George C. Apostolakis
FAA, NAFEC
Bldg. 14, Room 203, ANA-100
Atlantic City, NJ 08405

Mr. Dennis R. Asher
Bell Telephone Labs
3 Indiana Trail
Hopatany, NJ 07843

Mr. Robert Aston
Raytheon
Hartwell Road
Bedford, MA 01730

Mr. Roger G. Atchison
US Navy
NWSED, NAS Cecil Field
Jacksonville, FL 32215

Mr. Shinji Atoh
Tanegashima Space Center,
National Space Development
Kagoshima JAPAN

Mr. Eric Aubrey
Canadair Ltd.
Box 6087
Montreal, CANADA H3C 3G9

Mr. Robert J. Auburn
Airline Pilots Association
1625 Massachusettes Ave. N.W.
Washington, DC 20036

Mr. John E. Baker
Baker Lightning Rod Protection
34 May Street
Webster, NY 14580

Mr. Duel R. Ballard
Naval Air Systems Command
JP-2, Air-5321D
Washington, DC 20361

Mr. Robert Baran
Science Application, Inc.
8330 Old Court House Road
Vienna, VA 22180

Mr. Ray Barkalow
Consultant
4601 N. Park Avenue #720
Chevy Chase, MD 20015

Mr. James L. Barragree
Beech Aircraft Corp.
9709 E. Central
Wichita, KS 67201

Mr. George Bechtold
Naval Surface
Weapons Center
Silver Spring, MD 20903

Mr. Norman F. Bechtold
Joint Tact Comm (Tri-Tac) OFC
TT-E-SS
Ft. Monmouth, NJ 07703

Mr. Lewis E. Becker
Kentron International, Inc.
2345 W. Mockingbird Lane
Dallas, TX 75235

Mr. Brian L. Beers
Science Applications, Inc.
8330 Old Courthouse Road, Suite 510
Vienna, VA 22180

Mr. Herman C. Belderok
Piper Aircraft
Eng'g. DOA
Vero Beach, FL 32960

Mr. Jack Bell
Federal Aviation Administration
601 E. 12th - Room 1625
Kansas City, MO 64106

Mr. Bruce Benson
Federal Aviation Administration
P.O. Box 14, 701 C. Street AAL-431
Anchorage, AK 99513

Dr. Rodney B. Bent
Atlantic Scientific Corp.
1901 N. A1A
Indian Harbour Beach, FL 32937

Mr. Bill Bergman
DCEC, R302
1860 Wiehle Avenue
Reston, VA 22090

Mr. S. W. Billingsley
National Weather Service
8060 13th Street
Silver Spring, MD 20910

Mr. Joel Bloom
Naval Intelligence Support Center
4301 Suitland Road
Washington, DC 20390

Mr. J. A. Bohay
Dep't of Transport
LIAE-Transport Canada Bldg.
Ottawa, Ontario, Canada K1A ON8

Mr. A. Thomas Bolt
US Army Engineer Division
Box 1600, HNDED-SR
Huntsville, AL 35807

Mr. Peter Bootsma
de Havilland Aircraft Canada, Ltd.
Garratt Blvd.
Downsview-Ontario, CANADA M3K 1Y5

Mr. Nick Boyiazis
Federal Aviation Administration
P. O. Box 92007, AWE-454
Los Angeles, CA 90009

Dr. Jack Brennan
University of Central Florida
Box 25000
Orlando, FL 32816

Mr. George E. Briggs
GTS-Sylvania, Inc.
189 "B" Street, (C5D-Bldg. 3)
Needham, MA 02194

Mr. Art Brockschmidt
Boeing Aerospace
P. O. Box 3999
Seattle, WA 98124

Mr. Michael Brooks
Planning Research Corp.
Systems Services Co., PRC-1217
Kennedy Space Center, FL 32899

Mr. Gary Brown
Lawrence Livermore Laboratory
P. O. Box 45
Mercury, NV 89023

Mr. W. H. Brown
NASA
109 Claridge
Satellite Beach, FL 32937

Lt. Rodolfo H. Bruce
US Air Force
HQ Air Weather Service/LGL
Scott AFB, IL 62225

Mr. Herbert G. Bryant
USAF
53 McClellan AFB
Sacramento, CA 95652

Mr. Donald T. Buckley
FAA-P. O. Box 20636
ASO-212
Atlanta, GA 30320

Mr. B. J. Burban
Lockheed-California Co.
P. O. Box 551, Dept. 73-51
Burbank, CA 91520

Mr. Donald J. Burchnell
Dan's Electric & Lightning Control
1828 N. Goldenrod Road
Orlando, FL 32807

Mr. Brian J.C. Burrows
Culham Lightning Studies Unit
Culham Laboratory
Abdingdon, Oxford, ENGLAND

Mr. Donald C. Caldwell
US Navy, Department - Navair
13209 Clifton Road
Silver Spring, MD 20904

Mr. Morris Campi
Harry Diamond Laboratories
2800 Powder Mill Road
Adelphi, MD 20783

Mr. Bruce Cardall
Martin Marietta
P. O. Box 5837, Sand Lake Rd., MP 246
Orlando, FL 32805

Mr. Andre Carlier
Cables De Lyon
Jean Jaures 35 382 0316
Bezons, France 95870

Mr. DeLynn C. Chamberlain
Holmes & Narver, Inc.
P.O. Box 14340
Las Vegas, NV 89114

Mr. Hsi-Tien Chang
Sandia Laboratories
P. O. Box 5800, Division 4362
Albuquerque, NM 87185

Mr. John T. Chasteen
American Telephone & Telegraph Co.
10 S. Canal
Chicago, IL 60606

Mr. John A. Chouinard
Harris Corporation
Palm Bay Road
Melbourne, FL 32901

Mr. Dexter K. Clamp
Mid Carolina Electric Corp.
P.O. Box 68
Lexington, SC 29072

Mr. O. Melville Clark
General Semiconductor Ind., Inc.
P. O. Box 3078
Tempe, AZ 85281

Mr. Graham A. Clarkson
TII Industries
100 N. Strong Avenue
Lindenhurst, NY 11757

Mr. Don W. Clifford
McDonnell Aircraft
P.O. Box 516
St. Louis, MO 63166

Mr. Jay Cline
Dayton Granger Aviation, Inc.
P. O. Box 14070, 812 N.W. 1st St
Ft. Lauderdale, FL 33302

Mr. Samuel Clyatt
NASA-VO
Vo-A
Kennedy Space Center, FL 32899

Mr. William E. Cobb
NOAA
R 31
Boulder, CO 80303

Mr. W. G. Codner
Civil Air Attache, British Embassy
3100 Mass Avenue, N.W.
Washington, DC 20008

Mr. J. H. Copeland
USAF/FIT/79
2273 NE 61st
Seattle, WA 98115

Dr. John C. Corbin, Jr.
AF Flight Dynamics Laboratory
AFFDL/FES
Wright-Patterson AFB, OH 45433

Mr. Paul M. Cork
Gates Learjet Corp.
Box 7707
Wichita, KS 67277

Mr. Richard M. Cosel
Florida Institute of Technology
P. O. Box 1150
Melbourne, FL 32901

Dr. George Costache
Bell-Northern Research
P.O. Box 3511, STN C
Ottawa, Ontario, CANADA K1Y 4H7

Mr. Fred W. Crenshaw
Federal Aviation Administration
800 Independence Avenue, S. W.
Washington, DC 20591

Mr. Keith E. Crouch
Lightning Technologies, Inc.
560 Hubbard Avenue
Pittsfield, MA 01201

Mr. Boyd Cullimore
Thiokol Corp.
Mail Stop 282 G, P. O. Box 524
Brigham City, UT 84302

Dr. Mat Darveniza
University of Florida
Gainesville, FL

Dr. Leonard DeVries
USAF
Patrick AFB, FL 32925

Mr. Lloyd G. Diehl
Naval Surface Weapons Center
F-32
Silver Spring, MD 20910

Mr. Joe Dillon
Federal Aviation Administration
2300 East Devon Avenue
Des Plaines, IL 60018

Mr. J. H. Dinius
M & O Vitro Services
Eglin AFB, FL 32542

Mr. Joe L. Downs
Federal Aviation Administration
2300 E. Devon (AGL-436)
Des Plaines, IL 60018

Captain James C. Dunn
US Air Force
3246 Test Wing/TEOF
Eglin AFB, FL 32542

Mr. Lowell E. Earl
USAF/AFISC SESD
1365 Knoll Road
Redlands, CA 92373

Mr. Ted T. Ebina
FAA, NW Region
9010 E. Marginal Way, ANW-213
Seattle, WA 98108

Mr. Jack Edwards
RADC
RBCA
GAFB, NY 13401

Mr. Charles L. Elmore
Federal Aviation Administration
3400 Whipple Street, ASO 441-6
Atlanta, GA 30520

Mr. Richard E. Enstice
Director of Continuing Education
Florida Institute of Technology
Melbourne, FL 32901

Mr. Richard J. Fisher
Kaman Sciences Corp.
1500 Garden of the Gods Road
Colorado Springs, CO 80933

Mr. Donald R. Fitzgerald
Air Force Geophysics Lab.
LYW Hanscom AFB
Bedford, MA 01731

Mr. E. G. Fitzgerald
Harris Corp.
P.O. Box 37
Melbourne, FL 32901

Mr. Henry P. Fleming, Jr.
Naval Air Systems Command
JP-2, Air-52026 A
Washington, DC 20361

Mr. John D. Franklin
FAA-AWE-434
15000 Aviation Blvd.
Hawthorne, CA 90260

Mr. Raymond D. French
ECI Division E Systems, Inc.
MS 19, 1501 72nd Street, N.
St. Petersburg, FL 33733

Mr. Glen N. Fruktow
3901 W. Broadway
Hawthorne, CA 90250

Mr. Ryotaro Fukui
Oki Electric Industry Company, LTD.
1-9-6 Kohnan
Minato-Ku, Tokyo JAPAN

Mr. Gerhard Fussmann
USAF - AFISC/SESO
Norton AFB, CA 92409

Mr. Steve Galagan
Antennas for Communications, Inc.
486 Cypress Road
Ocala, FL 32670

Mr. Frank J. Galuppo
Grumman Aerospace Corp.
So. Oyster Bay Road, C02-25
Bethpage, NY 11714

Mr. William P. Geren
Boeing Commercial Airplane Co.
P. O. Box 3707, M/S 47-47
Seattle, WA 98124

Mr. William J. Getson
Harris GESD
P.O. Box 37
Melbourne, FL 32901

Mr. David V. Gonshov
Martin Marietta Corp.
P.O. Box 179, D 8350
Denver, CO 80201

Mr. L. D. Gore
COMSAT
950 L'Enfant Plaza, S.W.
Washington, DC 20024

Mr. Jose Maria Borger Goulart
Embraer
Brig. Faria Lima No. 2170
Sao Jose, Dos Campos, San Paulo BRAZIL

Mr. Elmer C. Graesser
Hercules Incorporated
P. O. Box 98
Magna, UT 84044

Mr. E. W. Gray
Bell Laboratories
6200 E. Broad Street
Columbus, OH 43213

Mr. Gordon K. Greene
Boeing Commercial Airplane Co.
P. O. Box 3707, M/S 64-15
Seattle, WA 98124

Mr. M. Emile Grenier
L.P. Grenier & Fils Inc.
4140 Blvd. Hamel, Ancienne-Lorette
Quebec, CANADA G2E 2H7

Mr. Donald K. Grimm
Collins Avionics
P. O. Box 1060
Melbourne, FL 32901

Mr. Mark Guidry
NASA-KSC
VE-GED-41
Kennedy Space Center, FL 32899

Mr. Manuel G. Guirior
Rockwell International
3370 Miraloma Avenue, P. O. Box 4192
Anaheim, CA 92686

Mr. James N. Gunter
MID Carolina Elect. Cooperative
P. O. Box 68
Lexington, SC 29072

Mr. Mitchell A. Guthrie
Naval Surface Weapons Center
N-42
Dahlgren, VA 22448

Mr. Robert L. Hammack
AT & T Co.
100 Edgewood Ave. NE
Atlanta, GA 30337

Mr. Omar Hancock
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

Mr. Robert D. Harger
Harger Lightning Protection, Inc.
551 North Avenue
Libertyville, IL 60048

Mr. James S. Harris
Federal Aviation Administration
P. O. Box 20636, ASO-431.8
Atlanta, GA 30320

Mr. Norman H. Haskell, Jr.
Southern Bell Tel & Tel Co.
1645 Hampton Street, #502
Columbia, SC 29201

Mr. J. Edmund Hay
U. S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, PA 15213

Mr. Richard H. Hazelton
Holmes & Narver, Inc.
P.O. Box 14340
Las Vegas, NV 89114

Mr. Kenneth Heary
Heary Bros. Light. Prot. Co., Inc.
11291 Moore Road 716-941-6141
Springville, NY 14141

Mr. Thomas H. Herring
Boeing Aerospace Company
P. O. Box 3999
Seattle, WA 98124

Mr. Lloyd J. Hess
Canadair Ltd.
P. O. Box 6087
Montreal, Quebec CANADA

Mr. Edwin F. Hiner
National Weather Service
8060 13th Street, W514
Silver Spring, MD 20910

Mr. Rolf E. Hoegberg
High Voltage Research Inst.
Uppsala University S 75590
Uppsala, Sweden

Mr. Robert N. Hokkanen
Naval Training Equipment Center
Code N411
Orlando, FL 32813

Mr. Jimmy Huang
Federal Aviation Administration
15000 Aviation Blvd. AWE - 453
Hawthorne, CA 90261

Mr. Howard H. Hubbard
Antennas for Communications, Inc.
486 Cypress Road
Ocala, FL 32670

Dr. G. Keith Huddleston
Georgia Institute of Technology
Atlanta, GA 30332

Mr. Anthony J. Iacono
Naval Air Systems Command
A 52026D
Washington, DC 20361

Mr. George M. Ishii
Litton Data Systems
8000 Woodley Avenue
Van Nuys, CA 91409

Ms. Karen K. Jablonski
FIT Student
2342 S. Bignonia Street
Melbourne, FL 32901

Mr. William Jafferis
NASA-KSC
VO-A
Kennedy Space Center, FL 32899

Mr. John R. James
Federal Aviation Administration
P. O. Box 20636
Atlanta, GA 30320

Mr. C. M. Jenkins
TII Ind., Inc.
P. O. Box 768
Leesburg, FL 32748

Mr. Reid Jeppsen
Thiocol Corp.
Mail 282 G, P. O. Box 524
Brigham City, UT 84302

Mr. Alan K. Johnson
Lockheed Missiles & Space Co.
Dept. 62-25, P. O. Box 504
Sunnyvale, CA 94088

Dr. Richard L. Johnson
Southwest Research Institute
6220 Culebra Road, Div. 16
San Antonio, TX 78284

Mr. Wesley R. Johnson
Boeing Wichita Company
3801 S. Oliver, MS K60-52
Wichita, KS 67210

Mr. William B. Johnson
CDR-USA MIRADCOM
ATTN: DRC PM-PE-EC
Redstone Arsenal, AL 35809

Mr. Gary M. Jones
U.S. Army Engineer District
210 N. 12th Street
St. Louis, MO 63101

Mr. Clarence W. Kaiser
Federal Aviation Administration
P. O. Box 20636, ASO-213
Atlanta, GA 30320

Mr. Joseph W. Kaiser
Federal Aviation Administration
601 E. 12th Street
Kansas City, MO 64119

Mr. Walter Karpowski
Digital Equipment Corp.
129 Parker Street, PK 3-2/S20
Maynard, MA 01754

Mr. Chester J. Kawiecki
Lightning Protection Corp.
P. O. Box 6086
Santa Barbara, CA 93111

Mr. William Kehrer
Air Force Weapons Lab.
87110 E
Kirtland AFB, NM 87110

Mr. Robert M. Keith
Martin Marietta Aerospace
P. O. Box 179
Denver, CO 80201

Mr. John M. Kennedy
PAFB
TOEP Bldg. 981
Patrick AFB, FL 32925

Mr. Harry W. Kennelty
US Army, CoE
Federal Regional Center
Thomasville, GA 31792

Mr. Edwin L. Kesler
Naval Electronic Systems Command
Code 52021
Washington, DC 20360

Mr. Thomas C. King
Walt Disney World
P. O. Box 40, Dept 784
Lake Buena Vista, FL 32830

Mr. J. B. Kinghorn
Mid-Carolina Electric Cooperative
P. O. Box 68
Lexington, SC 29072

Mr. Richard Kirchofer
Martin Marietta
P. O. Box 5837, MP 246
Orlando, FL 32805

Mr. Jonathan L. Kirkman
American Tel & Tel
100 Edgewood Avenue, N.E.
Atlanta, GA 30303

Mr. Ken Kite
Tektronix
3320 Holcomb Br. Rd.
Norcross, GA 30092

Mr. Francis J. Klapp
US Department of Army, FORSCOM
Ft. McPherson, GA 30330

Mr. Paul Knight
Consultant-EMC
816 N. E. Pecan Circle
Sebastian, FL 32958

Mr. Henry Knoller
Lockheed
Dept. 72-71 Bldg. 310
Burbank, CA 91520

Mr. Robert V. Kolar, P. E.
The Coloney Company
P. O. Box 5258
Tallahassee, FL 32301

Mr. C. S. Kwok
Chinese Civil Aviation Authority
Taiwan, ROC

Mr. Thomas J. Lange
Boeing Aerospace Company
P. O. Box 3999, MS 43-56
Seattle, WA 98124

Mr. Pierre Laroche
ONERA
29, Avenue de la Division Leclerc
Chatillon, France 92320

Mr. Norman Le Vine, P.E.
US Army Corps of Engineer's
P. O. Box 1600, West Station
Huntsville, AL 35807

Mr. John J. Leahy
FAA, ANE-436
12 New England Executive Park,
Burlington, MA 01803

Mr. Philippe Lecat
French DOD Service Technique
129 Rue de la Convention
Paris, France 75015

Mr. Carl L. Lennon
NASA
TI-INS-32
Kennedy Space Center, FL 32899

Mr. Frank R. Leslie
Harris GISD
P.O. Box 37 Bldg. 19/442
Melbourne, FL 32901

Mr. David K. Lewis
Department of Chemistry
Colgate University
Hamilton, NY 13346

Dr. Louis F. Libelo
NAVSWC
White Oak
Silver Spring, MD 20910

Mr. Jon M. Linke
Piper Aircraft Corp.
2560 Skyway Drive
Santa Maria, CA 93454

Dr. Philip F. Little
Culham Laboratory
Abingdon
Oxforshire, ENGLAND 0X3 14DB

Mr. Curtis V. Lochman
Det 1, SAMTEC/TOEIL
Patrick AFB, FL 32925

Mr. Wilton Lock
NASA, Dryden Flight Research Center
P. O. Box 273
Edward AFB, CA 93523

Mr. Donald F. Loomis
Federal Aviation Adm.
P. O. Box 92008-AWE 434
Los Angeles, CA 90009

Mr. Nels A. Lovegren
NASA
DL-NED-11
Kennedy Space Center, FL 32780

Mr. Albert F. Lowas, Jr.
US Air Force
438th Civil Engineering Squadron/DEEE
McGuire AFB, NJ 08641

Prof. Stig Lundquist
High Voltage Res. Inst.
Upsala University
S 5590, Upsala Sweden

Mr. Melvin B. Luxenberg
FAA
2300 E. Devon
Des Plaines, IL 60018

Capt. James K. Lyon, Jr.
HQ AWS/LGL
Scott AFB, IL 62225

Mr. Peter J. Madle
TRW
One Space Park
Redondo Beach, VA 90278

Mr. Theodore M. Madzy
IBM Corp.
P. O. Box 6, D67/5E09
Endicott, NY 13760

Mr. Thomas Mahoney
Dayton T. Brown Co.
Church Street
Bohemia, NY 11716

Mr. Michael W. Maier
NOAA/NHEML, Gables Avenue Tower
1320 S. Dixie Highway, Room 613
Coral Gables, FL 33146

Mr. Larry D. Malir
Cessna Aircraft Company
P. O. Box 7704
Wichita, KS 67277

Mr. Vernon L. Mangold
USAF
Wright Patterson AFB
WPAFB, OH 45433

Mr. S. N. Mapes
RCA Aerostat Systems
P. O. Box 4008
Patrick AFB, FL 32925

Mr. R. P. Massey
Bell Telephone Labs
Whippany Road
Whippany, NJ 07981

Mr. K. J. Maxwell
Technology/Scientific Services,
3840 New Germany Trebein Road
Dayton, OH 45431

Mr. Ted McClure
Motorola Communications
P. O. Box 1920
Decatur, GA 30031

Mr. John C. McKechnie
Naval Training Equipment Ctr.
Code N411
Orlando, FL 32813

Mr. Edward S. Mead
TRW
San Bernardino, CA 72346

Mr. R. R. Meek
Lockheed Ga. Co.
86 South Cobb Drive D/72-39 Z 316
Marietta, GA 30060

Mr. John M. Mercer
Naval Weapons Engineering Support
Bldg. 220, Rm. 310, Air 55/ESA-132
Washington, DC 20374

Mr. Terry J. Michaud
Department of Transport (Canada)
Transport Canada Building, TAQR
Ottawa, CANADA K1A 0N8

Mr. Harry Miller
Sussex
New Brunswick, Canada

Mr. Irving Mindel
IIT Research Institute
10 W. 35th Street
Chicago, IL 60616

Mr. Irving W. Moody
Beach Aircraft Corp.
9709 E. Central
Wichita, KS 67207

Mr. Robert Morrissette
Harris Corp. (Gov't Systems)
Box 37
Melbourne, FL 32901

Mr. Daniel R. Mullin
Naval Air Engineering Center
ESSD, Code 9313
Lakehurst, NJ 08733

Mr. Roy Murphy
Mitre Corp.
Box 208
Bedford, MA 01730

Dr. Rama C. Murty
Department of Physics
University of Western Ontario
London, Ontario, CANADA N6A 3K7

Mr. John W. Naglich
FAA
3400 Whipple Street, ASO 442
Atlanta, GA 30320

Mr. Earl M. Neve
FAA-ASO 441-61
P. O. Box 20636
Atlanta, GA 30320

Mr. Dennis Newton
Lear Avia Corp.
P. O. Box 60000
Reno, NV 89506

Mr.. Richard D. Nussbaum
U. S. Naval Air Development Center
Mail-Code 20P3
Marminster, PA 18974

Mr. Donald H. O'Bryhim
Naval Electronic Systems Command
Code 51032 DO
Washington, DC 20360

Mr. Richard Odenberg
Transtector Systems
532 Monterey Pass Road
Monterey Park, CA 91754

Mr. Sy Oyoung
The Boeing Company
8433 SE 33rd Place
Mercer, WA 98040

Mr. Robert Padula
FIT Student
230 Prince Street
Melbourne, FL 32901

Mr. Joe Palandrani
Atlantic Scientific Corp.
1901 N. A1A
Indian Harbour Beach, FL 32937

Mr. Jack Parker
FAA, ASW 442
4400 Blue Mound Road
Ft. Worth, TX 76101

Mr. Leo J. Paquette
Federal Aviation Administration
2641 E. Buckeye Road, PHX TSO
Phoenix, AZ 85034

Mr. G. W. Parkinson
Sikorsky Aircraft
N. Main Street
Stratford, CT 06497

Mr. Richard L. Pearce
Pan American World Airways, Inc.
MU 840
Patrick AFB, FL 32925

Prof. Warren D. Peele
Purdue University
West Lafayette, IN 47907

Mr. Jean Marie Piduch
STNA
246 rue Le Courbe
Paris, France 75015

Capt. Donald W. Pittman
HQ AWS/DOQS
Scott AFB, IL 62225

Mr. William E. Pittman
Holmes & Narver, Inc.
P.O. Box 14340
Las Vegas, NV 89114

Mr. Felix L. Pitts
NASA Langley Research Center
Langley Station - MS 477
Hampton, VA 23692

Mr. J. Anderson Plumer
Lightning Technologies, Inc.
560 Hubbard Avenue
Pittsfield, MA 01201

Dr. Horst A. Poehler
RCA
RCA-620
Kennedy Space Center, FL 32899

Captain Elton Pollock
USAF
3246 Test Wing, TEOF
Eglin AFB, FL 32542

Mr. William T. Pope
Marelco 99 Electronics
4399 N. Harbor City Blvd.
Melbourne, FL 32935

Mr. F. Clark Price
Federal Aviation Administration
P. O. Box 20636, ASO 214
Atlanta, GA 30320

Mr. R. L. Prieto
C.P. Clare & Co.
3101 W. Pratt
Chicago, IL 60645

Mr. John Prodan
Institute of Atmospheric Sciences
S. Dakota School of Mines and Tech
Rapid City, SD 57701

Mr. John Proudfit
Interstate Electronics Corp.
707 East Vermont Avenue, D 4730
Anaheim, CA 92803

Mr. Dennis W. Quinn
Flight Dynamics Laboratory
Wright Patterson AFB
Dayton, OH 45433

Mr. J. Raney
Dayton Granger Aviation, Inc.
P. O. Box 14070, 812 N.W. 1st St
Ft. Lauderdale, FL 33302

Mr. Peter Ravenhill
Westinghouse Electric Corp.
P. O. Box 1897, MS 998
Baltimore, MD 21203

Mr. John E. Reed AFS-130
Federal Aviation Administration
800 Independence Avenue, S. W.,
Washington, DC 20591

Mr. W. Ramon Reel
Martin Marietta Aerospace
P. O. Box 5837, MP 171
Orlando, FL 32855

Mr. Thomas Reeves
ITT Telecommunications
2000 S. Wolf Road
Des Plaines, IL 60018

Dr. Andrew W. Revay, Jr.
Florida Institute of Technology
P. O. Box 1150
Melbourne, FL 32901

Mr. Welby T. Risler
NASA - US Gov't
TO-A
Kennedy Space Center, FL 32899

Mr. James D. Roland
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

Mr. John D. Robb
Lightning & Transients Research
2531 W. Summer Street
St. Paul, MN 55113

Captain P. L. Rustan
Department of Electrical Eng
University of Florida
Gainesville, FL 32611

Mr. Ralph Ruth
National Weather Service
8060 13th Street
Silver Spring, MD 20910

Mr. Charles A. Rychetsky
GTE Automatic Electric
688 Industrial Drive
Elmhurst, IL 60126

Mr. Fred Sakate
FAA
Washington, DC

Mr. Balwinder S. Samra, P.E.
United Telephone Co. of Ohio
665 Lexington Avenue
Mansfield, OH 44907

Mr. Al Schmidt
Honeywell, Inc
13350 US 19
St. Petersburg, FL 33733

Mr. J. G. Schneider
Technology/Scientific Services,
3840 New Germany Trebein Road
Dayton, OH 45431

Mr. Barry R. Schofer
Digital Equipment Corp.
146 Main Street, ML 8-4/H19
Maynard, MA 01754

Mr. Herman W. Schoob, Jr.
Naval Electronic Systems Eng
Goer Rd
Charleston, SC 29402

Mr. Jack Schroeder
Communications Components Corp.
3000 Airway Avenue
Costa Mesa, CA 92626

Mr. Timothy J. Seymour
WPAFB
1100 Medway Curlisle Rd.
Medway, OH

Mr. Arthur L. Sheldon
Harris Corp.
P. O. Box 37
Melbourne, FL 32901

Mr. M. W. Shores
General Dynamics
Box 2507
Pomona, CA 91766

Mr. Mitsuo Sibata
Civil Aviation Bureau M.O.T.
2-1-3 Kasumigaseki
Chiyoda-ku, Tokyo JAPAN

Mr. Louis J. Sillay
Harris Gov't Communications Sys
P. O. Box 37
Melbourne, FL 32901

Mr. Jay Silverberg
Today - Ass't Metro Editor
P.O. Box 330
Cocoa, FL 32922

Mr. Jean Pierre Simi
Les Cables De Lyon
65 Rue Jean Jaures
Bezons, FRANCE 95870

Mr. Irvin B. Slayton, Jr.
Harris Corp./GISD
P.O. Box 37
Melbourne, FL 32901

Mr. Kevin T. Smith
FIT (IEEE Student Branch)
FIT Box 6082
Melbourne, FL 32901

Lt. Lee O. Smith
Applied Technolgoy Labs
ATTN: DAVDL-ATL-ASA
Ft. Eustis, VA 23604

Mr. H. M. Smithgall
Nazlou Consulting
449 Atlnatis Drive
Satellite Beach, FL 32937

Mr. Joseph R. Soderquist
FAA
800 Independence Avenue, AFS-120
Washington, DC 20591

Mr. Richard P. Sowa
Federal Aviation Administration
P. O. Box 92007, AWE-454
Los Angeles, CA 90009

Mr. Loren J. Spencer
FAA-ASF 30
800 Independence Avenue
Washington, DC 20591

Mr. Robert J. Spinti
University of Wisconsin - Stout
Department of Energy & Transportation
Menomonie, WI 54751

Mr. James R. Stahmann
Planning Research Corp.
Systems Service Co., PRC-1217
Kennedy Space Center, FL 32899

Mr. Ronald B. Standler
University of Florida
216 Larsen Hall
Gainesville, FL 32611

Lt. Col. Benjamin Starling, M.C., T.D.
BLP Lightning Research
Long Clawson Manor, Nr. Melton Mowbray
Leicestershire, ENGLAND

Mr. William Statter AAF-530
Federal Aviation Administration
800 Independence Avenue, S.W.
Washington, DC 20591

Mr. John W. Stephens
Applied Technology Labs
ATTN: DAVDL-ATL-ASA
Ft. Eustis, VA 23604

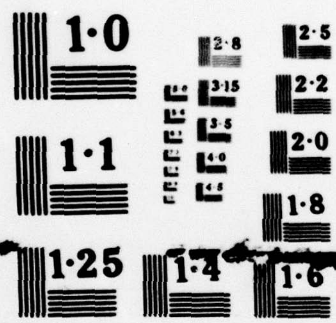
Mr. B. T. Stesen
Martin Marietta Aerospace
P. O. Box 5837
Orlando, FL 32808

AD-A070 779 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC SYSTEM--ETC F/G 4/1
FEDERAL AVIATION ADMINISTRATION - FLORIDA INSTITUTE OF TECHNOLO--ETC(U)
MAY 79

UNCLASSIFIED FAA-RD-79-6-SUPPL-1A NL

2 OF 2
AD
A070779

END
DATE
FILMED
8-79
DDC



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Dr. David Strawe
Boeing Aerospace Company
P. O. Box 3999
Seattle, WA 98124

Mr. Dwight L. Suiter
NASA WA3
Lyndon B. Johnson Space Center
Houston, TX 77058

Mr. Russell J. Tagliareni
Bureau of Aviation, Fla.
605 Suwannee Street
Tallahassee, FL 32304

Mr. Harry K. Tang
Planning Research Corp.
HDQ/RM 3338
Kennedy Space Center, FL 32899

Mr. William L. Taylor
NSSL
1313 Halley Circle
Norman, OK 73069

Mr. Mitchel E. Thomas
NASA
Langley Research Center
Hampton, VA 23185

Mr. Stanley J. Thomson
PRC Systems Services Co.
PRC-1217
Kennedy Space Center, FL 32899

Mr. Arthur P. Thornton
FAA, P. O. Box 92007
Worldway, AWE-453
Los Angeles, CA 90009

Mr. Gerry Tilkington
Gulf Stream America
P. O. Box 2206
Atlanta, GA 31402

Mr. Charles E. Touhy
Lockheed California Co.
19450 Citronia Street
Northridge, CA 91324

Mr. Lawrence E. Troy
GTE Sylvania, Inc.
100 First Avenue
Waltham, MA 02154

Mr. Robert L. Truax
The Truax Company
604 Danley Drive
Ft. Myers, FL 33907

Mr. Jack W. Tweedale RM 309
MN/DOT Transportation Bldg
St. Paul, MN 55155

Mr. Takashi Uchimura
Civil Aviation Bureau M.O.T.
2-1-3 Kasumigaseki
Chiyoda-ku, Tokyo JAPAN

Dr. Martin A. Uman
Department of Electrical Eng
University of Florida
Gainesville, FL 32611

Mr. E. F. Vance
SRI International
Rt. 3 Box 268 A
Fort Worth, TX 76140

Mr. John Velsor
Shaw Aero Devices, Inc.
E. Hampton, NY 11937

Mr. John F. Vonderembse
Westinghouse Electric Corp.
P. O. Box 989
Lima, OH 45802

Mr. Bo Wahlgren
Saab - Scania, AB/46/13/129020
Linkoping, Sweden S -581 88

Mr. George A. Wakefield
James G. Biddle Company
Township Line & Jolly Rds.
Plymouth Meeting, PA 19462

Ms. Jackie Walker
Atlantic Scientific Corp.
1901 N. AlA
Indian Harbour Beach, FL 32937

Mr. L. C. Walko
Technology/Scientific Services
3840 New Germany Trebein Road
Dayton, OH 45431

Mr. John M. Warren
Warren Lightning Rod Company
2 Richey Avenue
Collingswood, NJ 08107

Mr. Lloyd B. Watts
Army Corp of Engineers
Denver Federal Center
Denver, CO 80225

Dr. Harry P. Weber, Dean
School of Science & Engineering
Florida Institute of Technology
Melbourne, FL 32901

Mr. Gus Weinstock
McDonnell Aircraft
Box 516
St. Louis, MO 63166

Mr. Henry L. Weiss
FAA
2300 E. Devon
Des Plaines, IL 60018

Dr. Carrell D. Whitescarver
Martin Marietta Aerospace
P. O. Box 5837, MP-246
Orlando, FL 32855

Mr. Cliff Wiedman
Walt Disney World
P. O. Box 40, Dept. 784
Lake Buena Vista, FL 32830

Mr. Alan L. Wilcox
Scientific-Atlanta, Inc.
3845 Pleasantdate Road
Atlanta, GA 30340

Mr. C. L. Wilkerson, Jr.
Martin Marietta Aerospace
P. O. Box 5837, MP 246
Orlando, FL 32855

Mr. Rod L. Williams
Harris Corporation
Palm Bay Road
Palm Bay, FL 32901

Mr. O. W. Willingham
Southern Bell Telephone
609 400 Blvd.
Jacksonville, FL 32202

Mr. William P. Winn
New Mexico Inst. of Mining & Tech
Campus Station
Socorro, NM 87801

Mr. Ron Wojtasinski
NASA
Kennedy Space Center, FL 32899

Mr. Bernhard I. Wolff
General Electric
Electronics Park, Bldg. 7, MD 41
Syracuse, NY 13221

Mr. Gordon L. Wood
Cessna Aircraft Company
P. O. Box 1521
Wichita, KS 67201

Mr. James J. Wood
US Army Communications Command
130-228th Street, S.W.
Bothell, WA 98011

Mr. W. R. Woodruff
Hercules Inc.
P. O. Box 98
Bacchus, UT 84044

Mr. Jimmy A. Woody
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, GA 30332

Mr. Tom Wright
TACO
Egypt Road, RD 2
Newark, DE 19711

Mr. Y. C. Wu
Chinese Civil Aviation Authority
Taiwan, ROC

Mr. Takao Yasuda
Oki Electric Industry Company Ltd.
4-10-3 Shibaura, Minato-KU
Tokyo JAPAN

Mr. Satoshi Yokota
Ambraer-Empr. Brasileirade Aero.
21-5400 Ave. Brig. Faria Lima 2170
Sao Jose, San Paulo BRAZIL

Mr. Robert T. Zeitler
General Dynamics Corp.
P. O. Box 748 Mail Zone 2463
Fort Worth, TX 76101

Mr. John F. Zych
USAF AFCS 184 EEG/6182562661
2030 Ravenwood Drive, EEISG
Collinsville, IL 62234

Mr. Jan A. Zysko
U. S. Department of Commerce
3401 NW 59th Avenue
Miami, FL 33152